FEBRUARY 1959

JOURNAL OF THE IRON AND STEEL INSTITUTE

4 GROSVENOR GARDENS · LONDON SWI

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VOL. 191 PART 2

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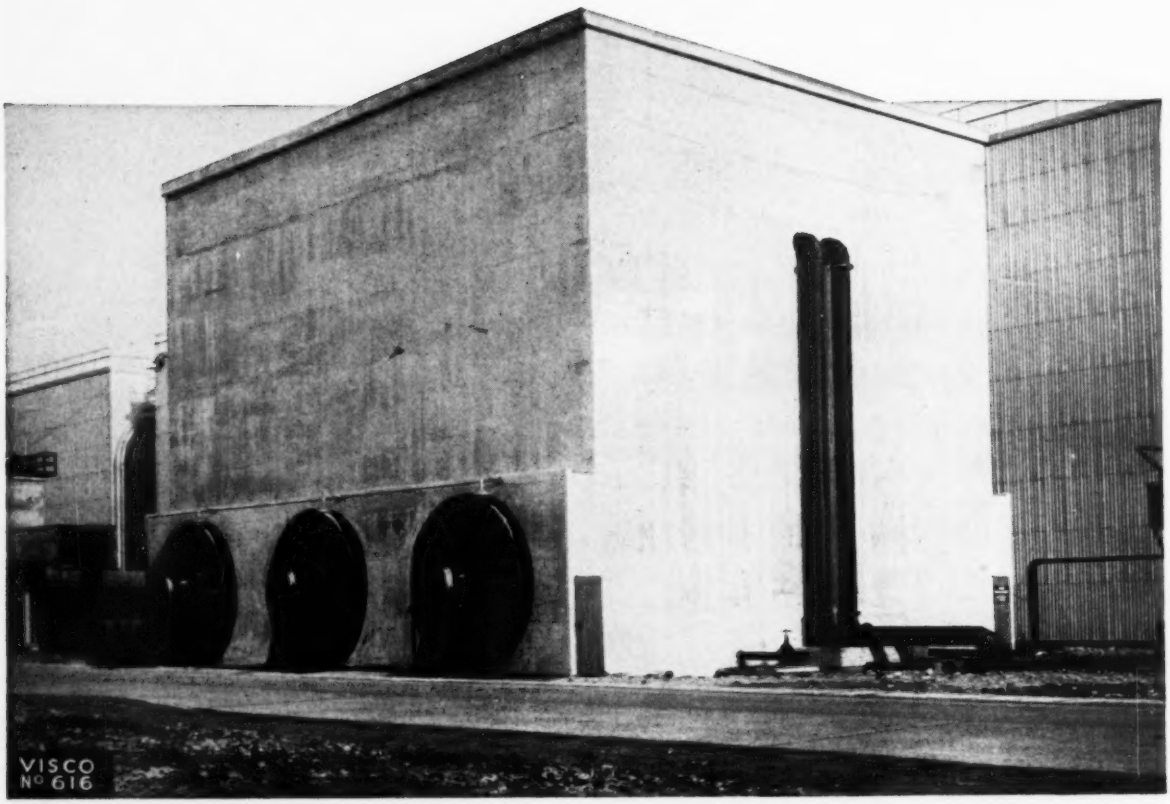

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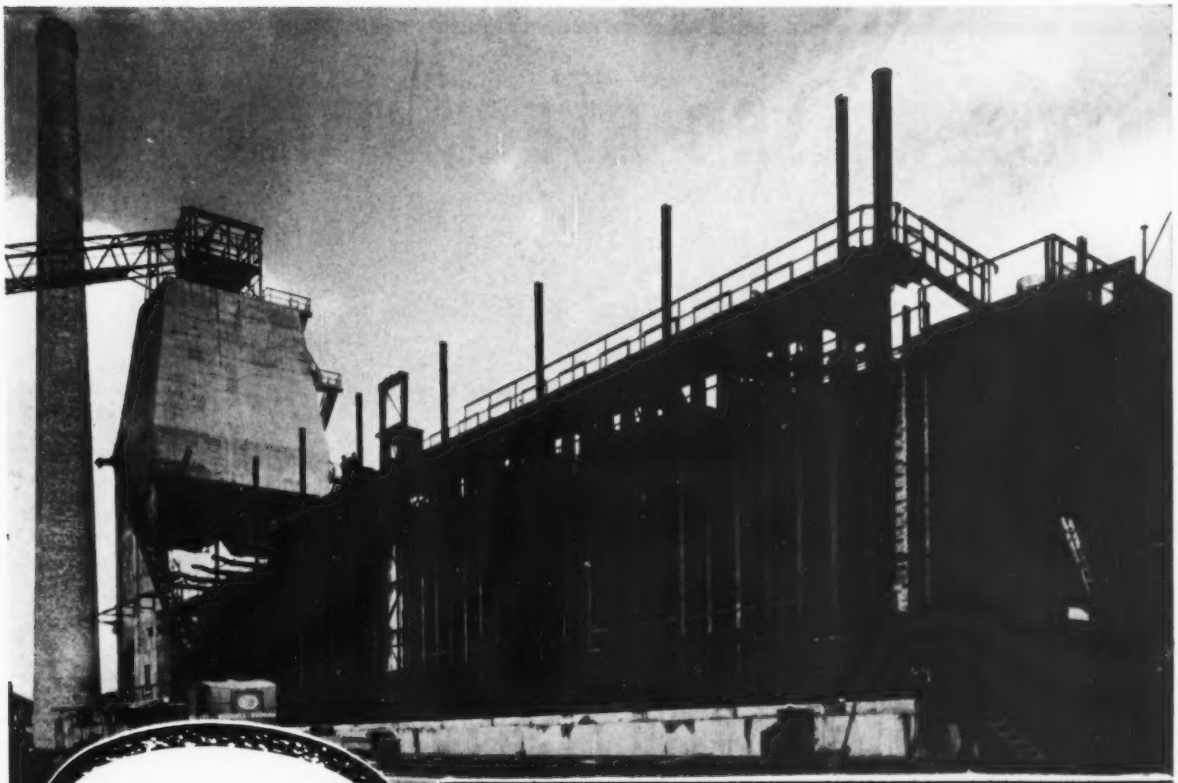

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42 OVENS

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SIXTH [illegible] INSTALLATION
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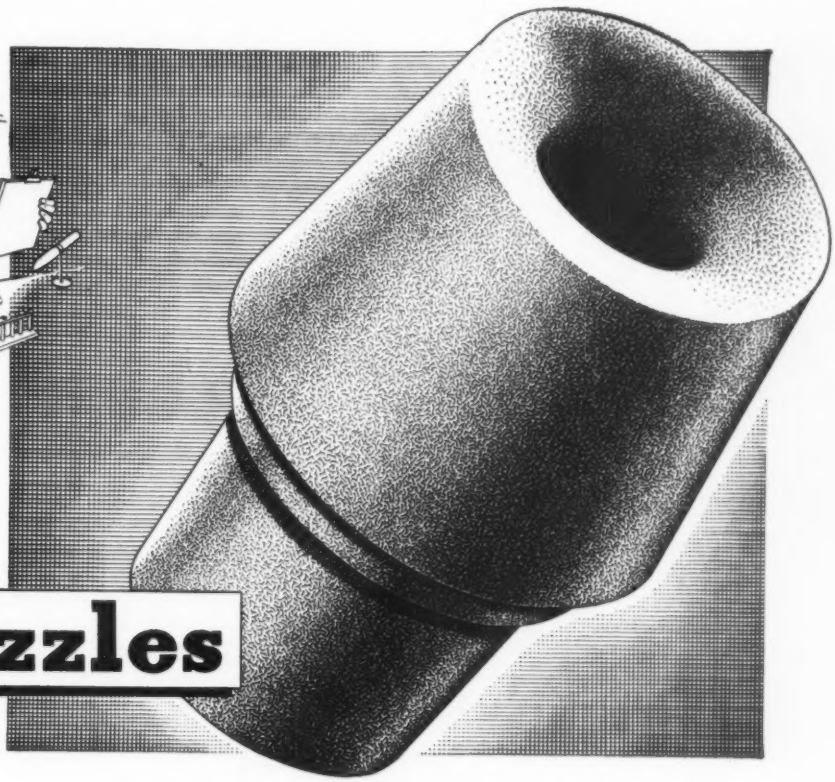

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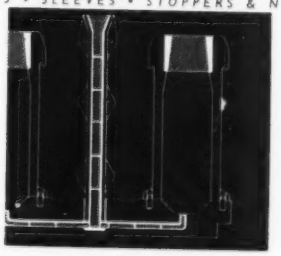

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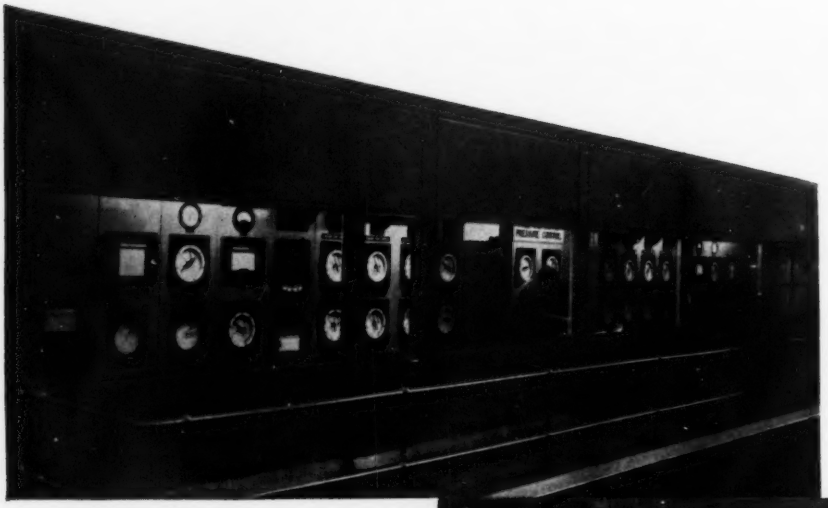

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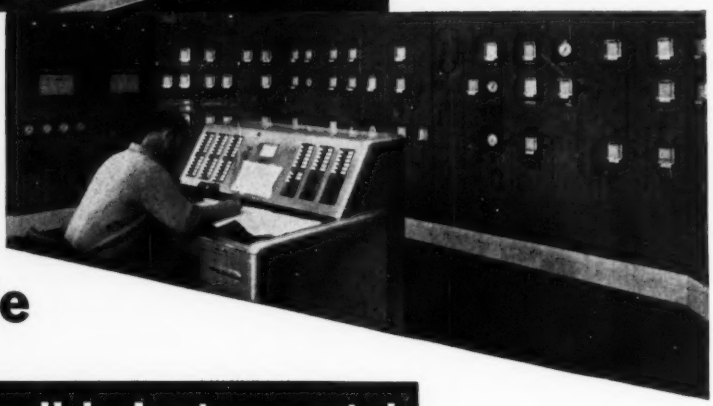

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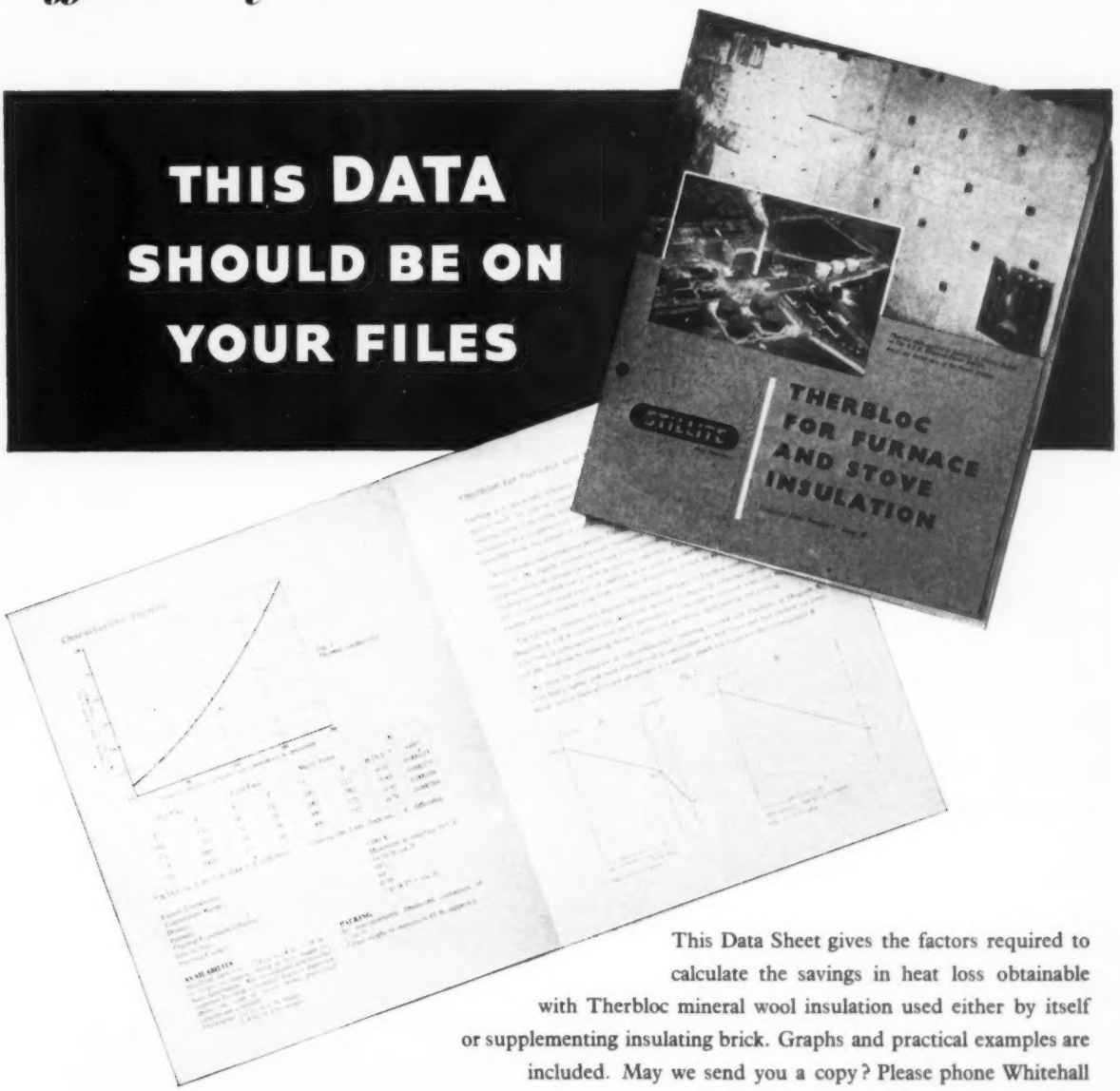

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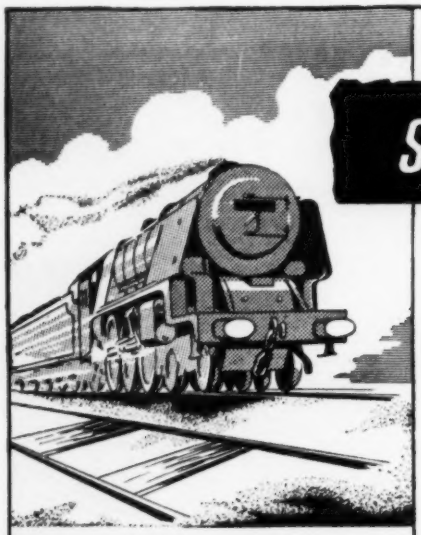

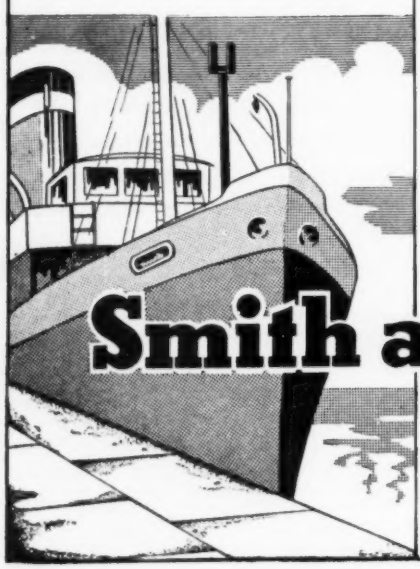

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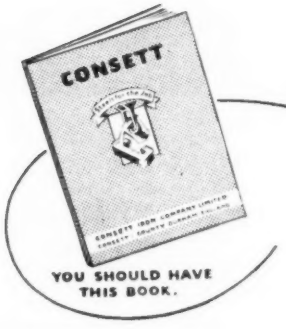

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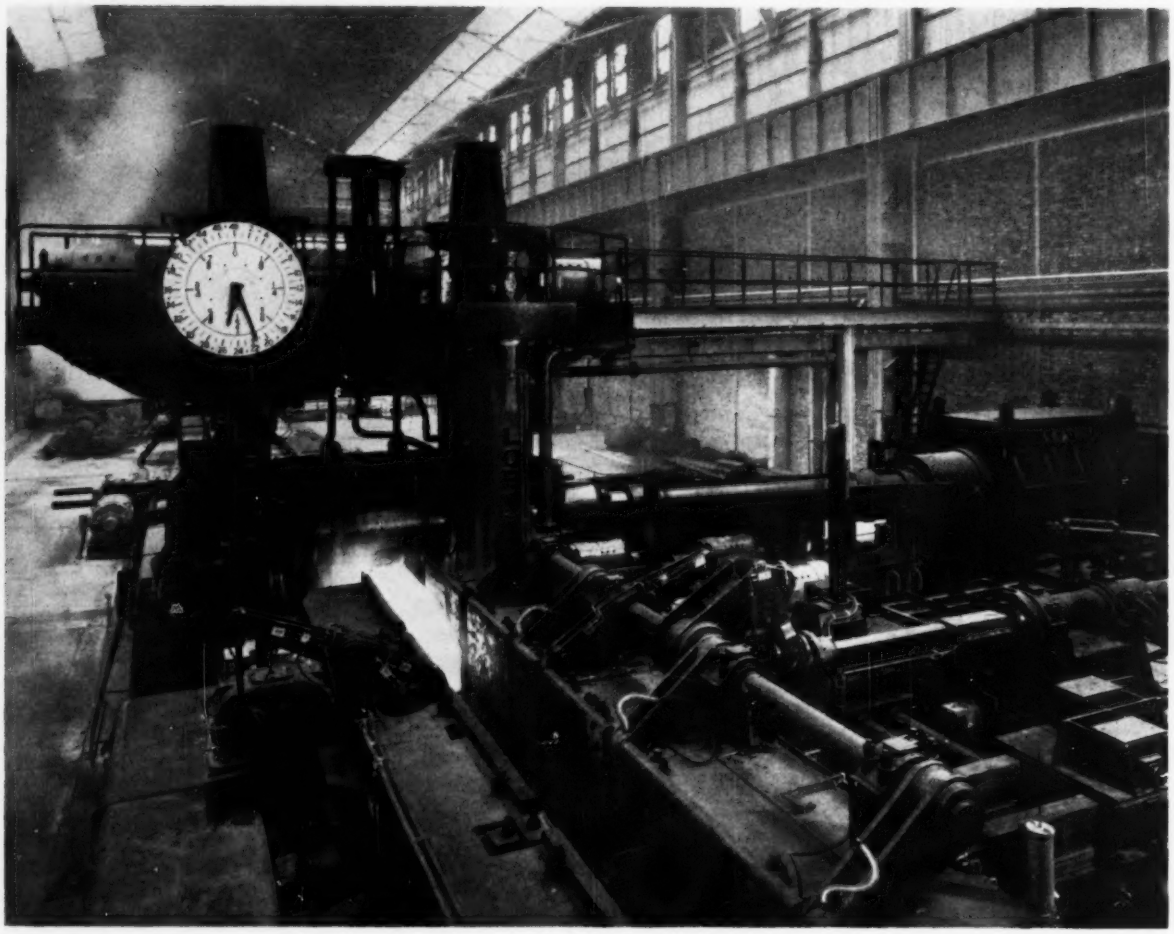

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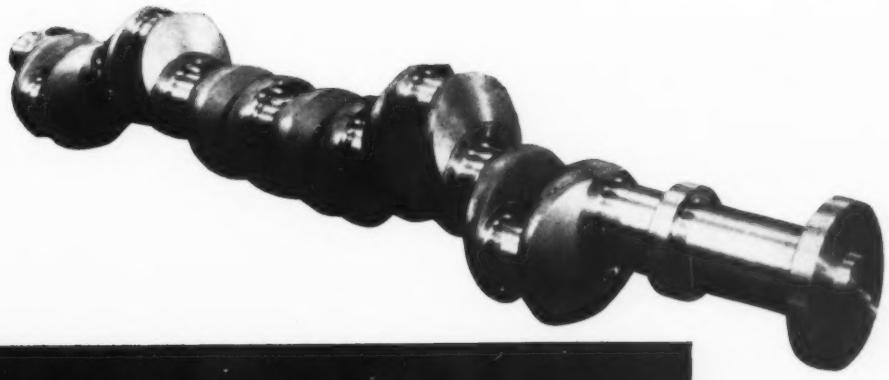

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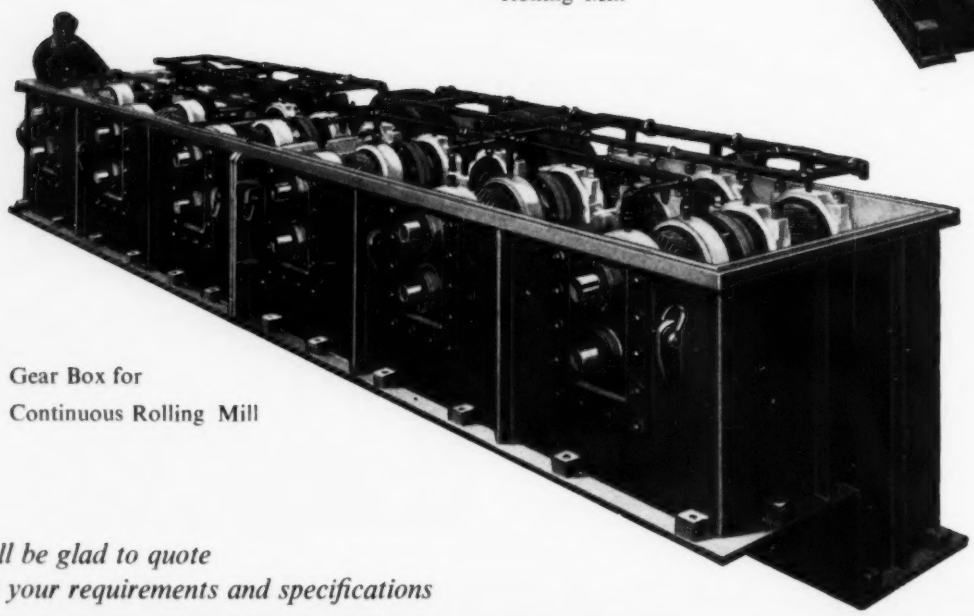

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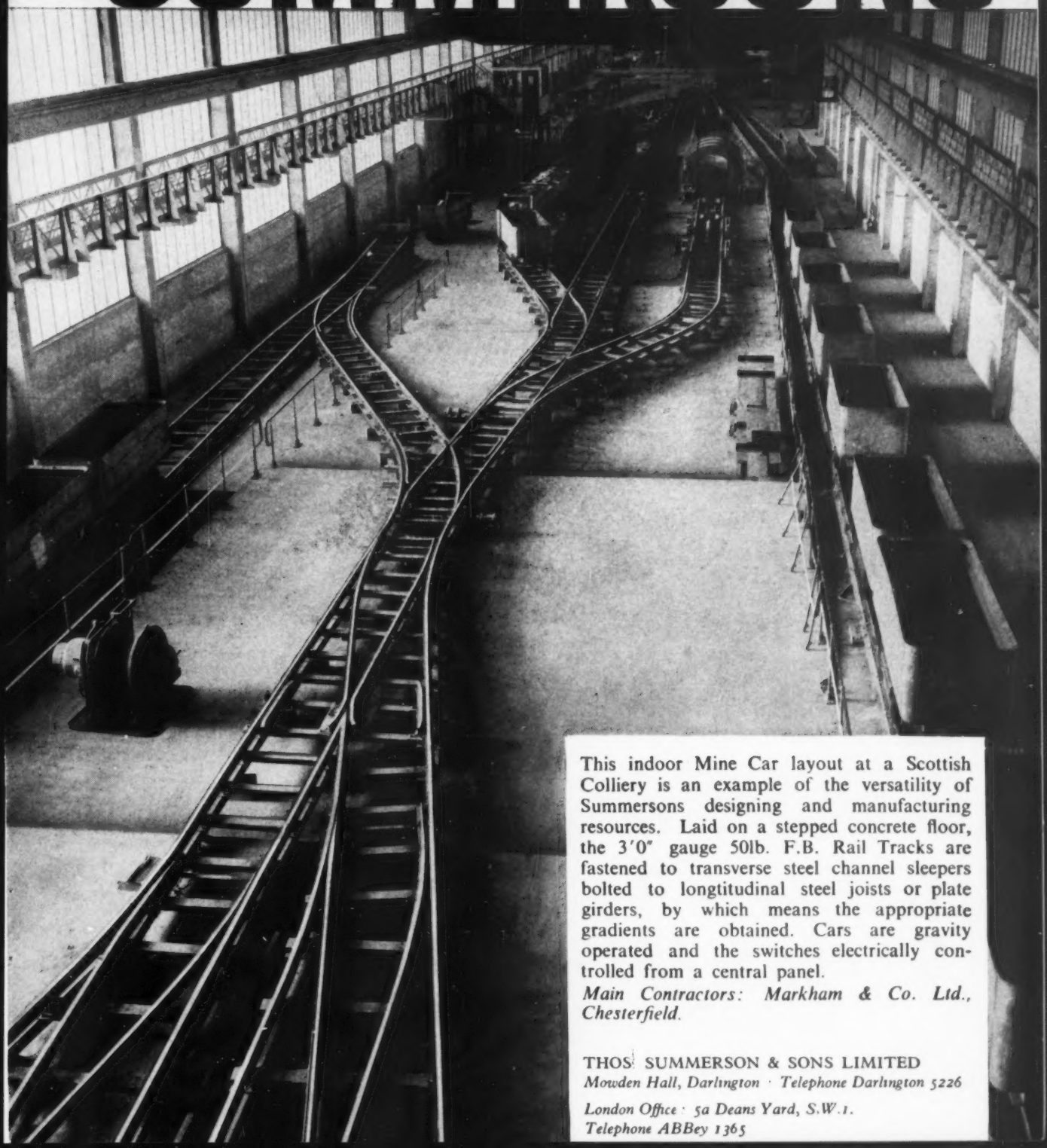

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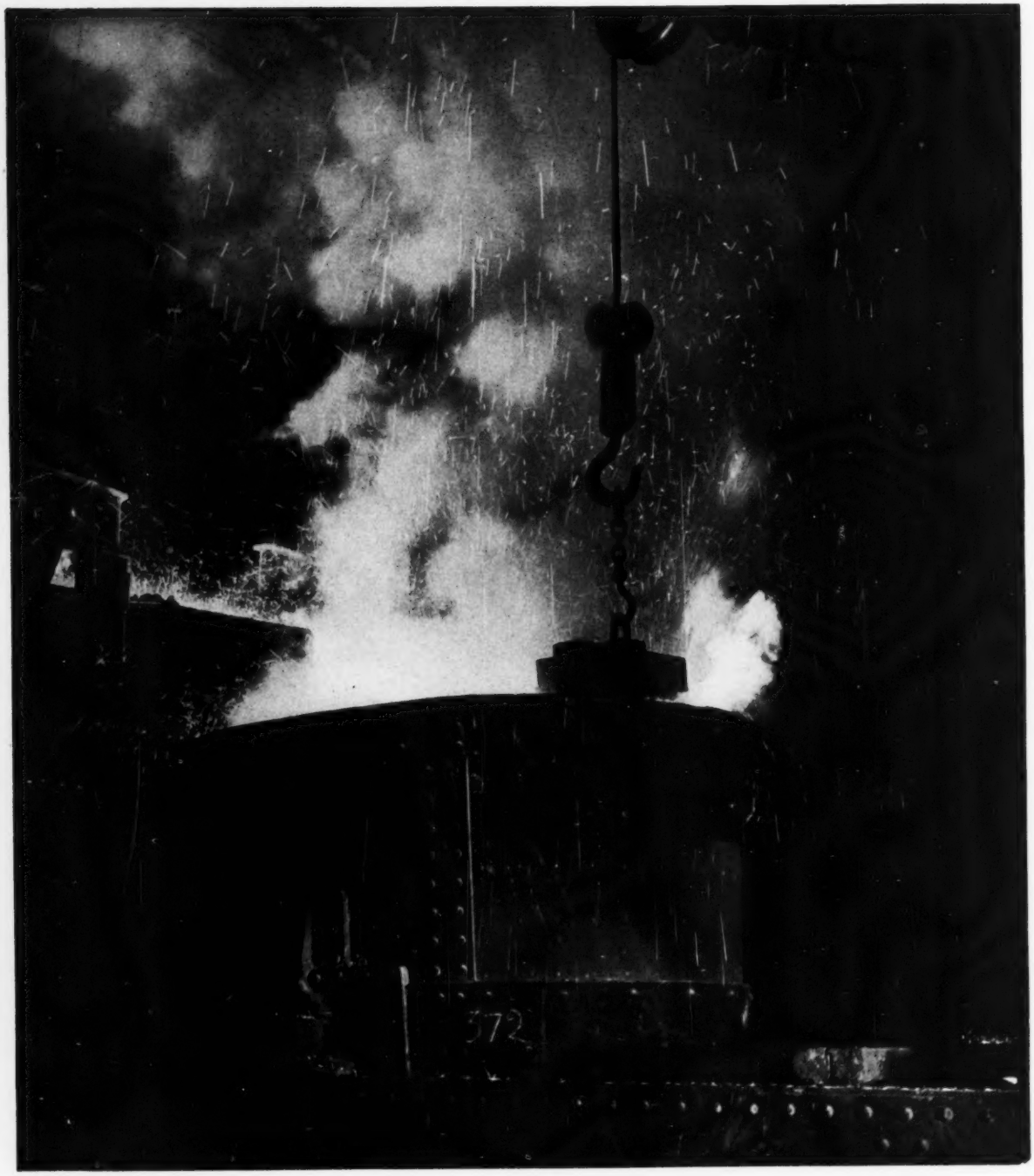

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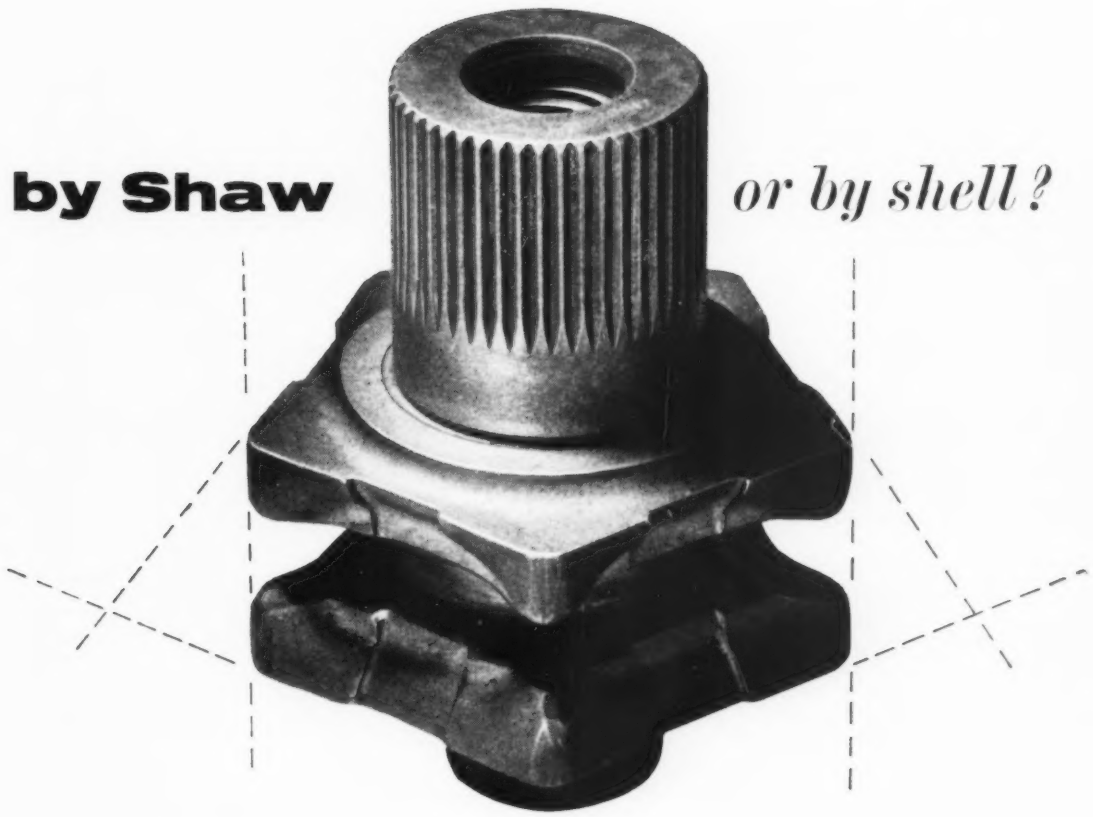

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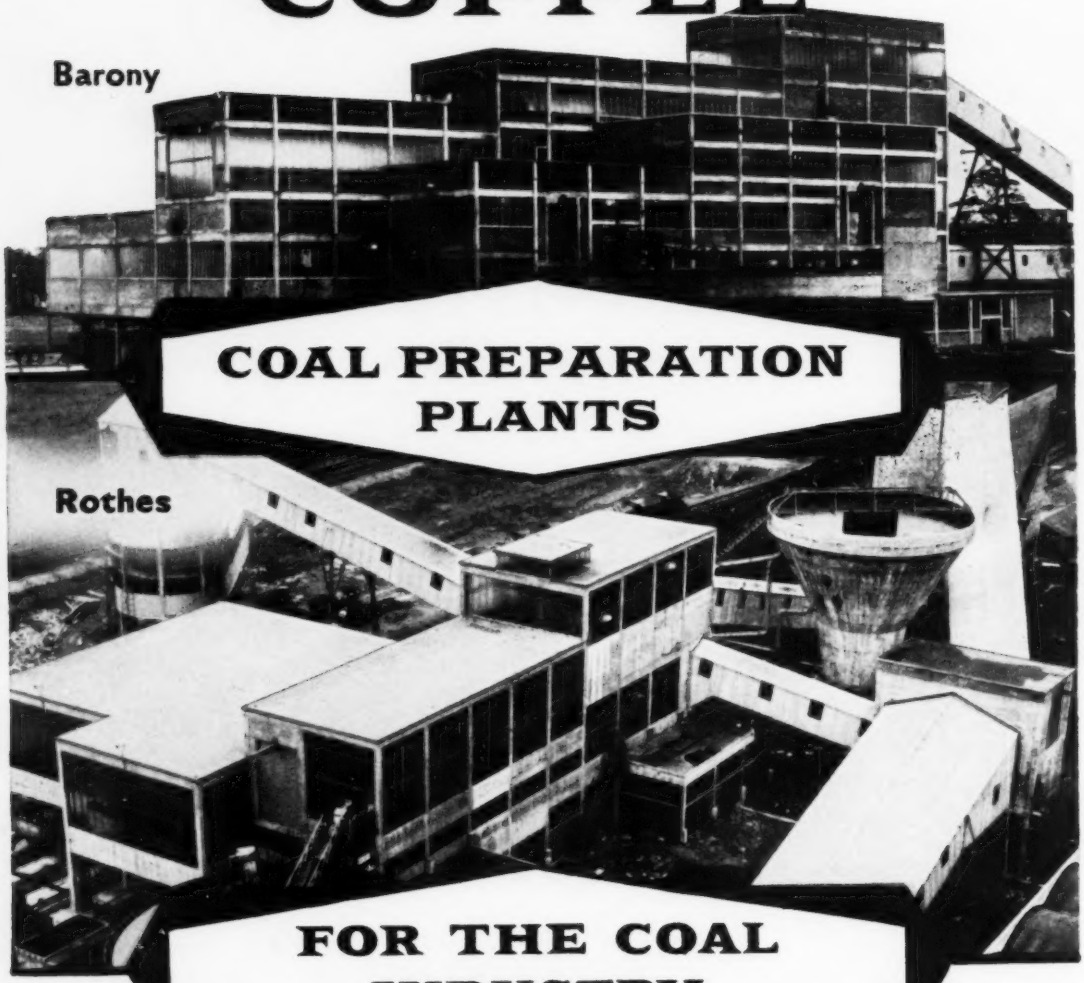

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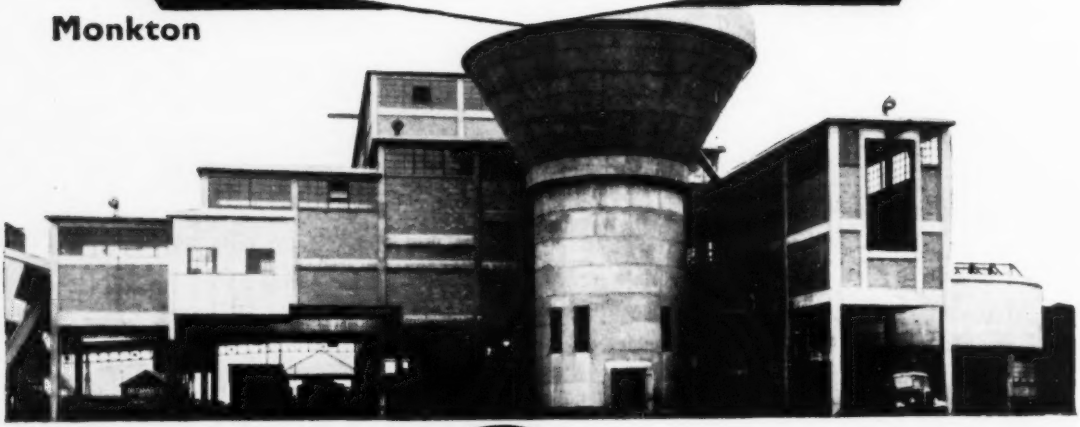

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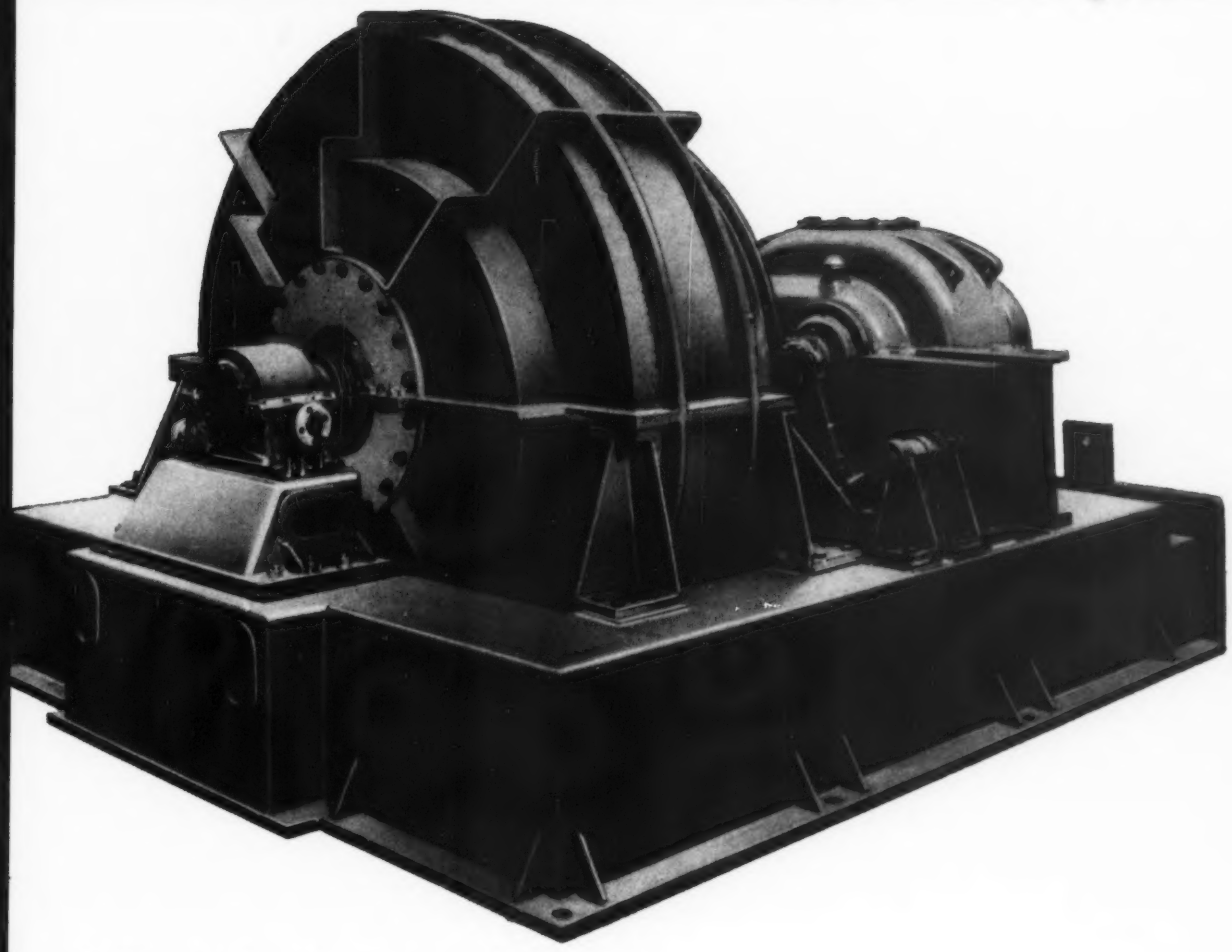

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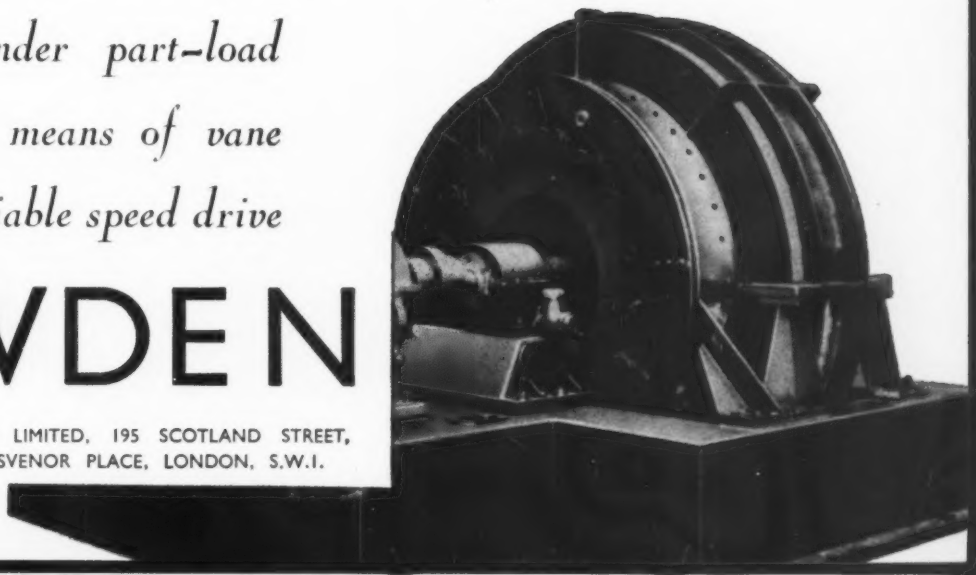

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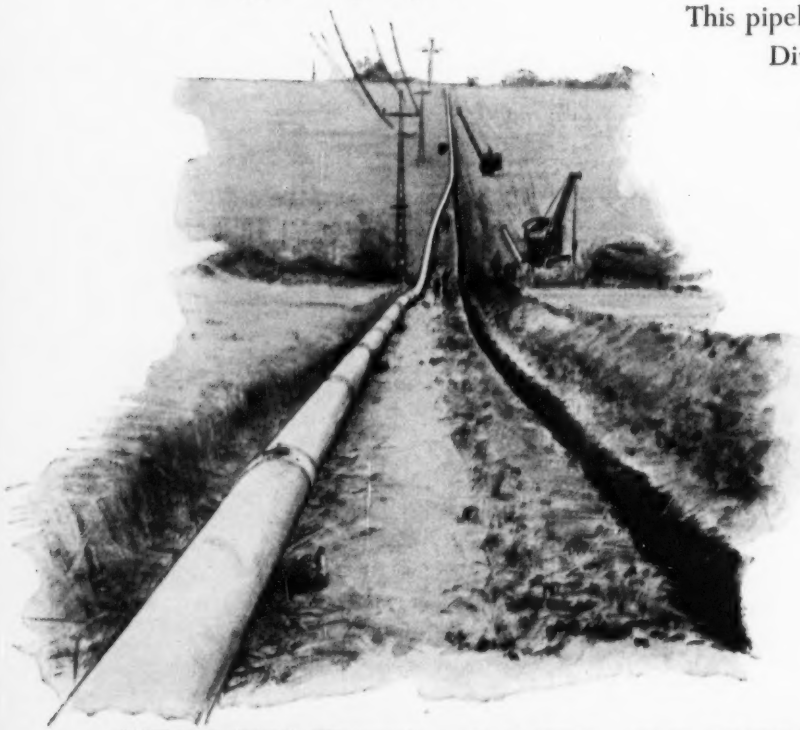
THE STEEL TUBE AGE

At top, welding the pipes. Below, welded pipeline, with part already in trench and rest ready for moving into place.



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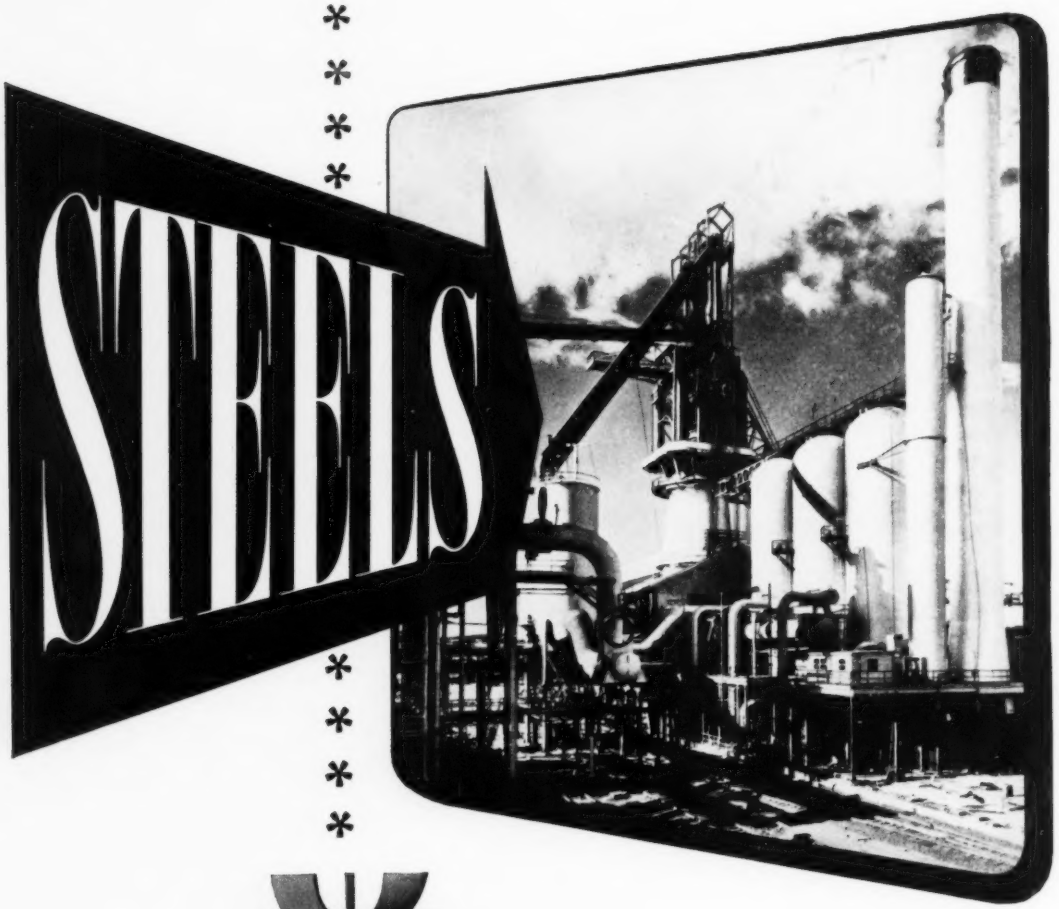

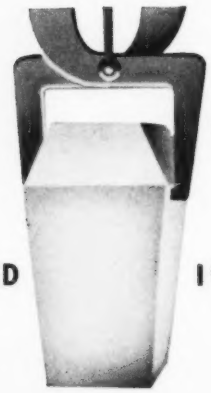

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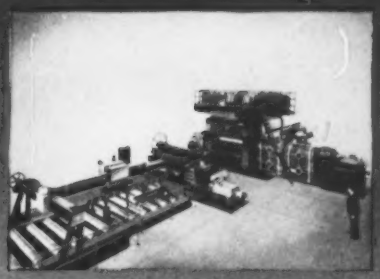

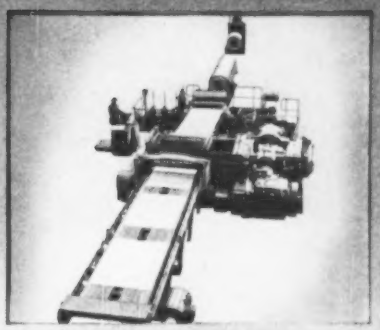

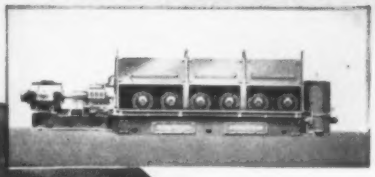

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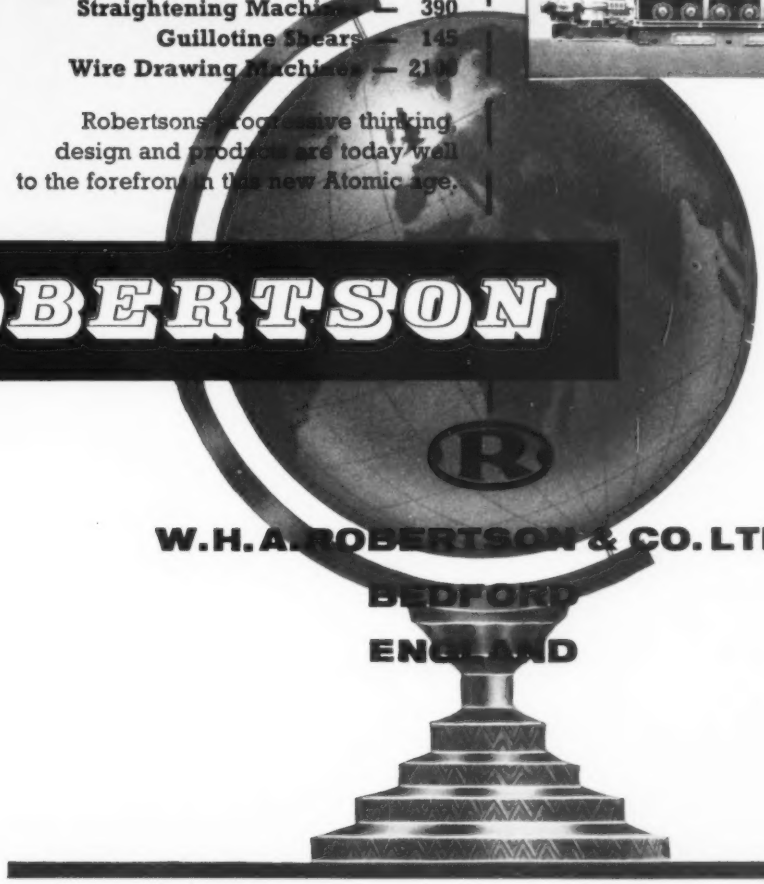

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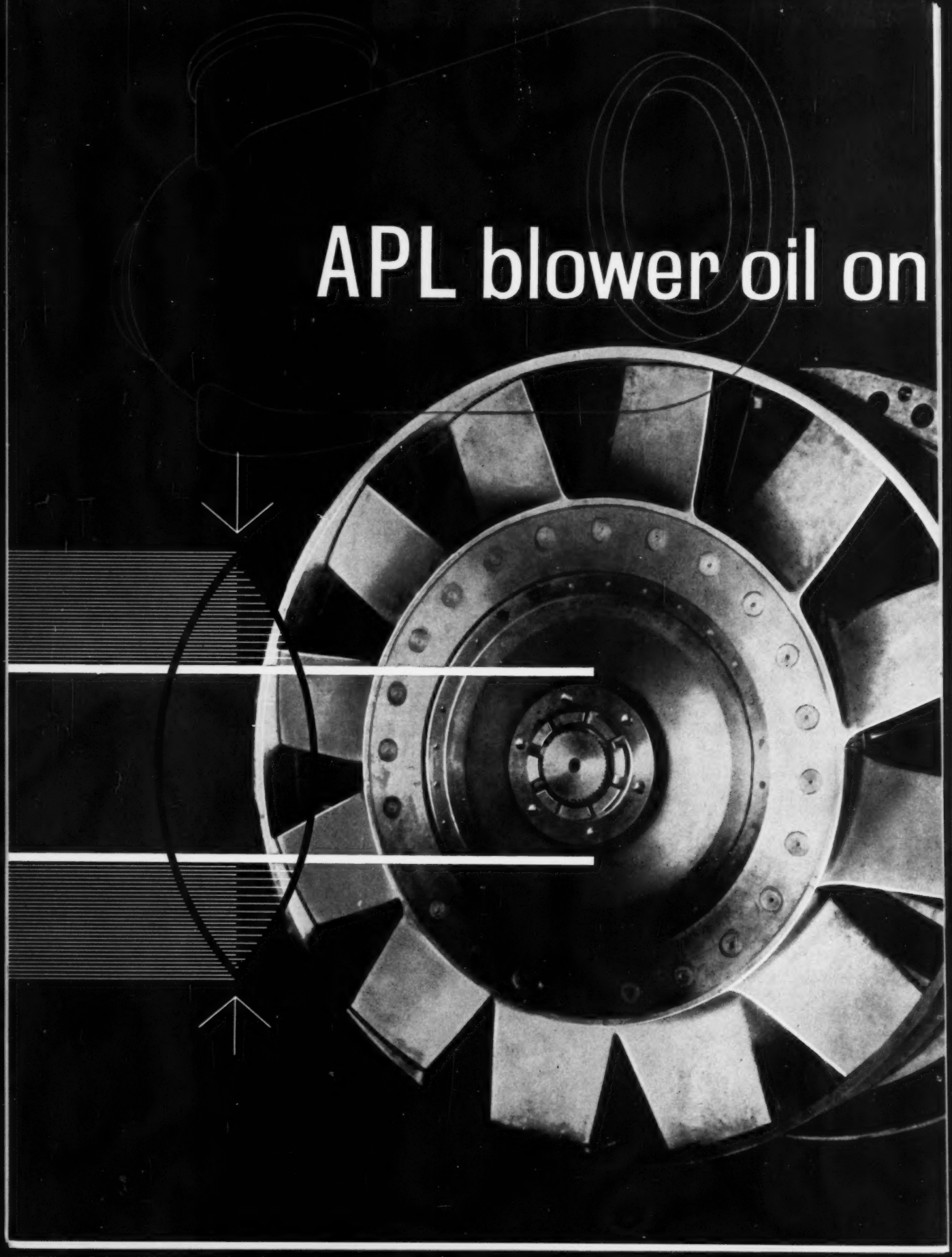


oil after radiation

Here was a problem of national importance. Lubricants were needed by the nuclear industry for reactor equipment, much of it subjected to radiation. Yet, like human beings, oils and greases were vulnerable to radiation. Oils darkened in colour and became coarse-grained solids (solidification being but one of a tangled skein of problems).

The Shell Group started working on the problems of lubricating under radiation conditions while most nuclear power stations were still on the drawing board. In fact, Shell was the first oil company to develop Atomic Power Lubricants, and the research that went into Shell A.P.L. is characteristic of the way Shell sets about doing things. A team of research workers was assembled at Shell's Research Centre at Thornton. Series of tests were carried out both in the B.E.P.O. pile at the U.K. Atomic Energy Authority Research Establishment, Harwell, and with Thornton's own Cobalt 60 source of radiation. In 1957, after four years of research, Britain's first range of Atomic Power Lubricants was on the market.

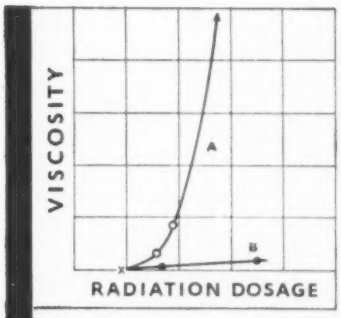
The moral of the A.P.L. story is that Shell research is supremely applicational. The Centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organisation have any major lubrication problems, it will pay you to get in touch with your local distributor of Shell Industrial Lubricants.

The Research Story

In the hundreds of complex hydrocarbons examined, very different reactions to radiation were observed according to the configuration of the atoms in the molecules. When carbon atoms were arranged in long, straight chains, radiation caused these chains to link up with one another, giving highly complex structures of an entirely different nature from the original material. The first effect of this change was to cause a rapid increase in viscosity, ultimately giving rise to a solid rubber-like product.

For example, a high quality turbine oil conforming to BSS.489 receiving a dosage of 1.77×10^{18} neutrons/cm² was changed into an intractable solid—a clear demonstration that radically new lubricants were needed by the nuclear industry.

Shell Atomic Power Lubricants have a molecular structure that has proved itself very resistant to radiation. In fact it will withstand a radiation dosage four million times stronger than that which will kill a man—without any significant change in structure or physical properties.



Relationship between radiation dosage and percentage increase in viscosity, cS at 100°F.
Oil A: high molecular weight long chain hydrocarbon. *Oil B:* Shell A.P.L. 731.

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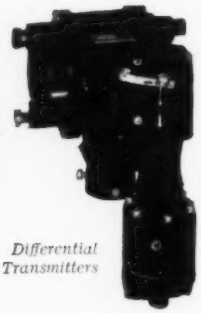

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Relays

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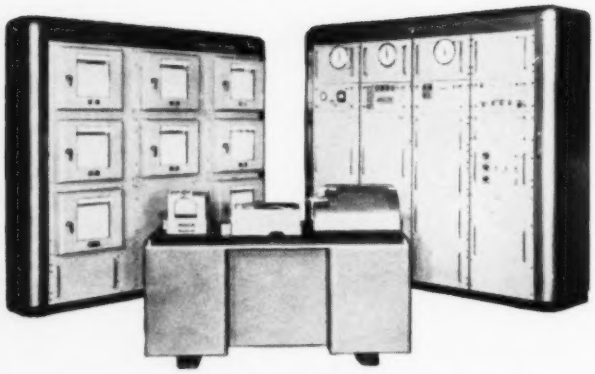

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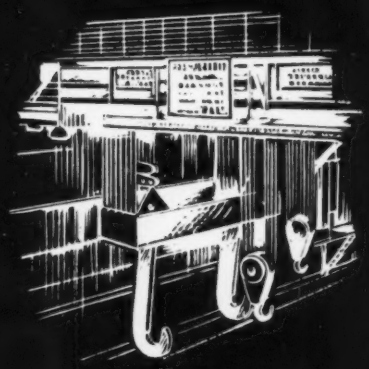
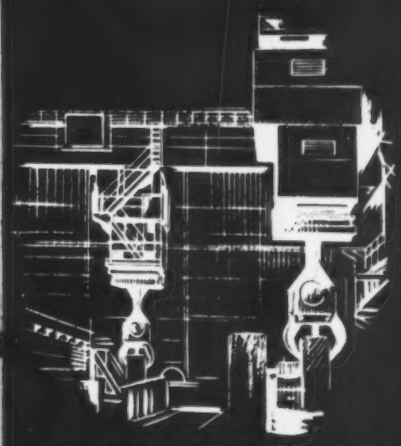
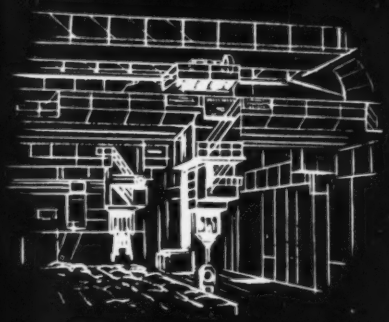


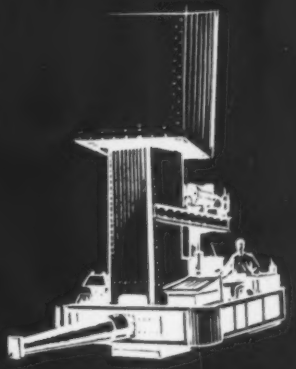
Ladle Cranes



Soaking Pit Cranes



Stripping Cranes



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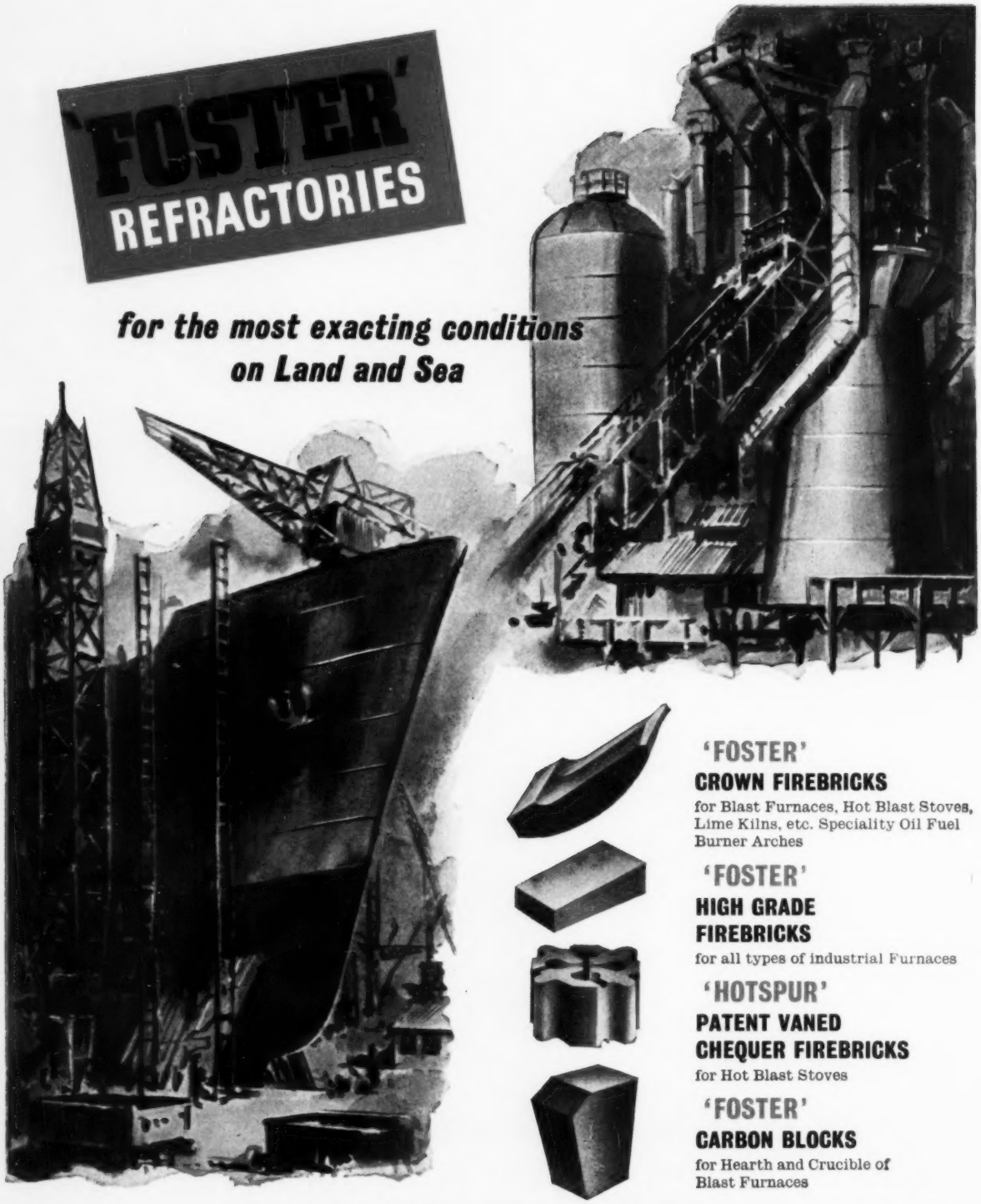

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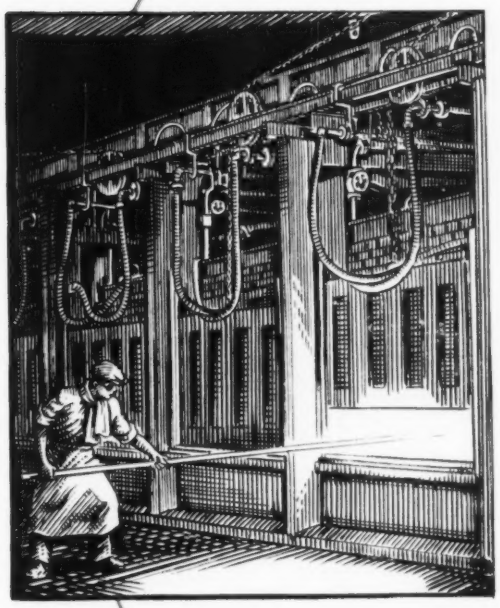

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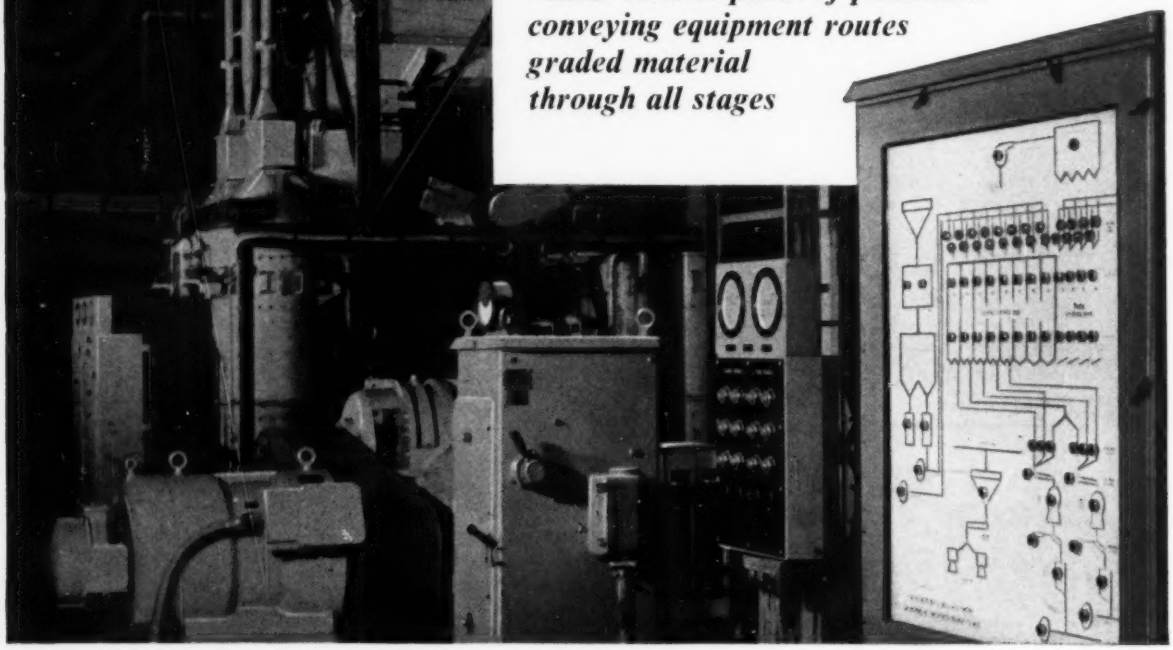

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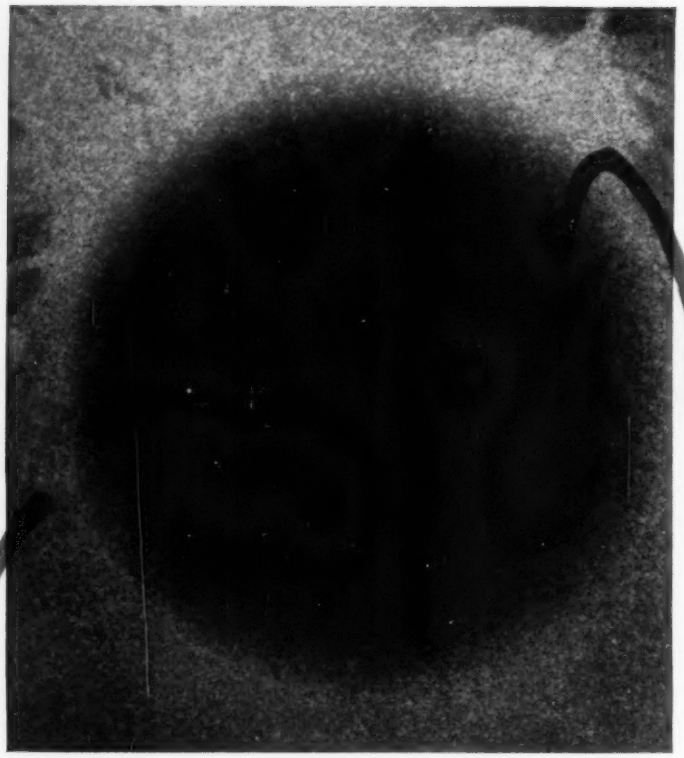

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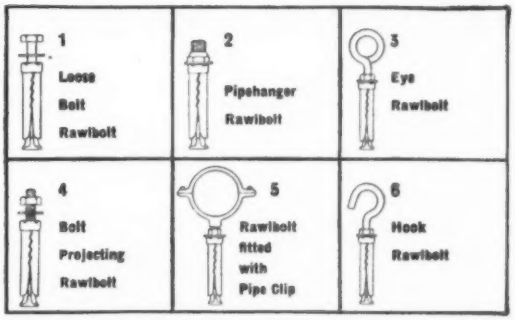

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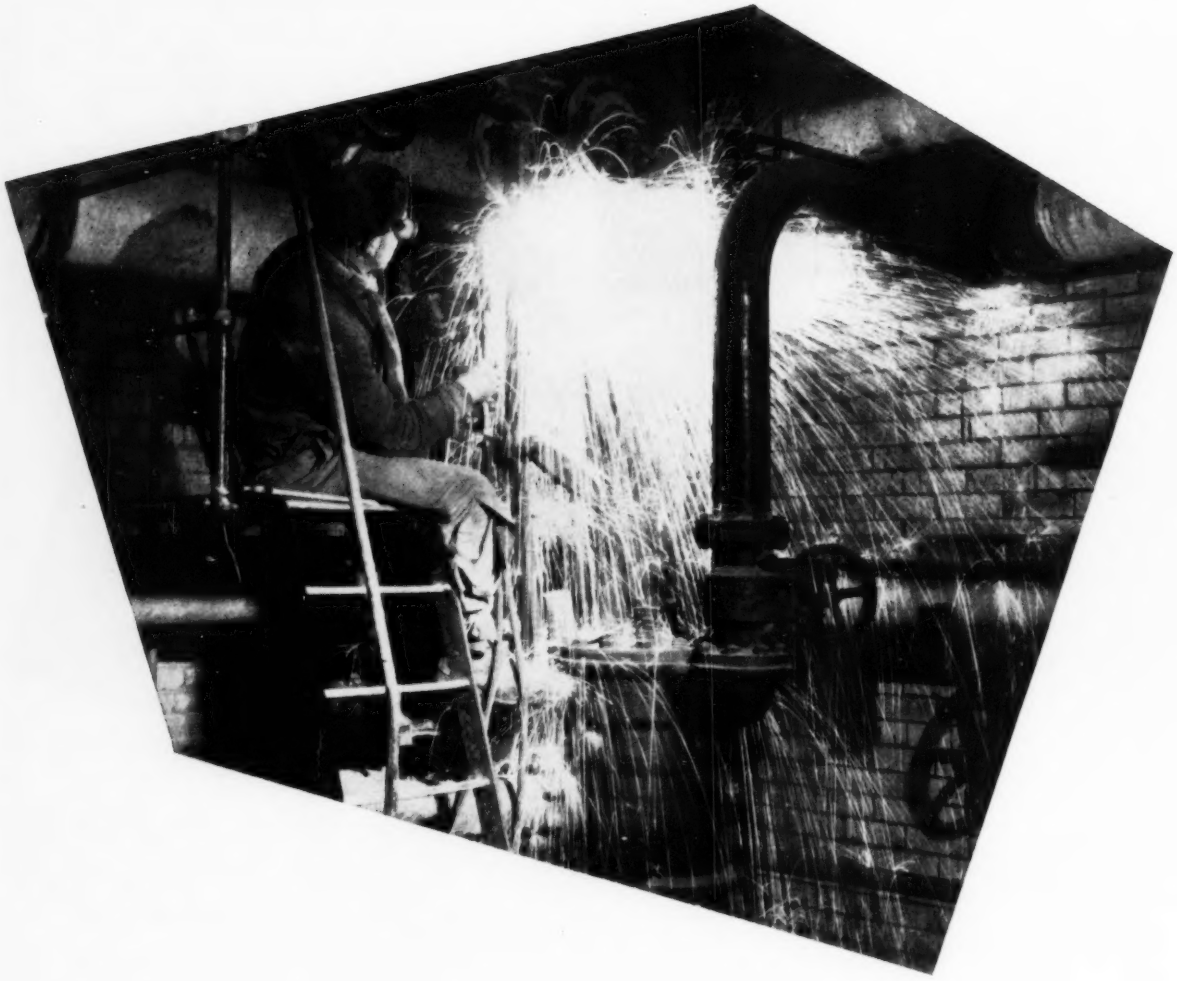

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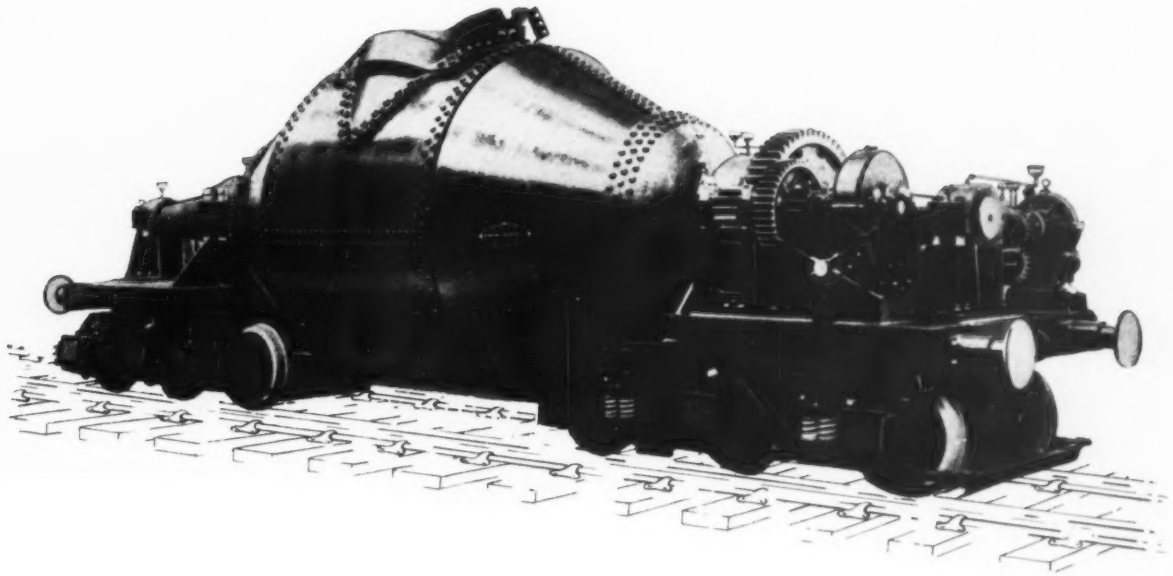

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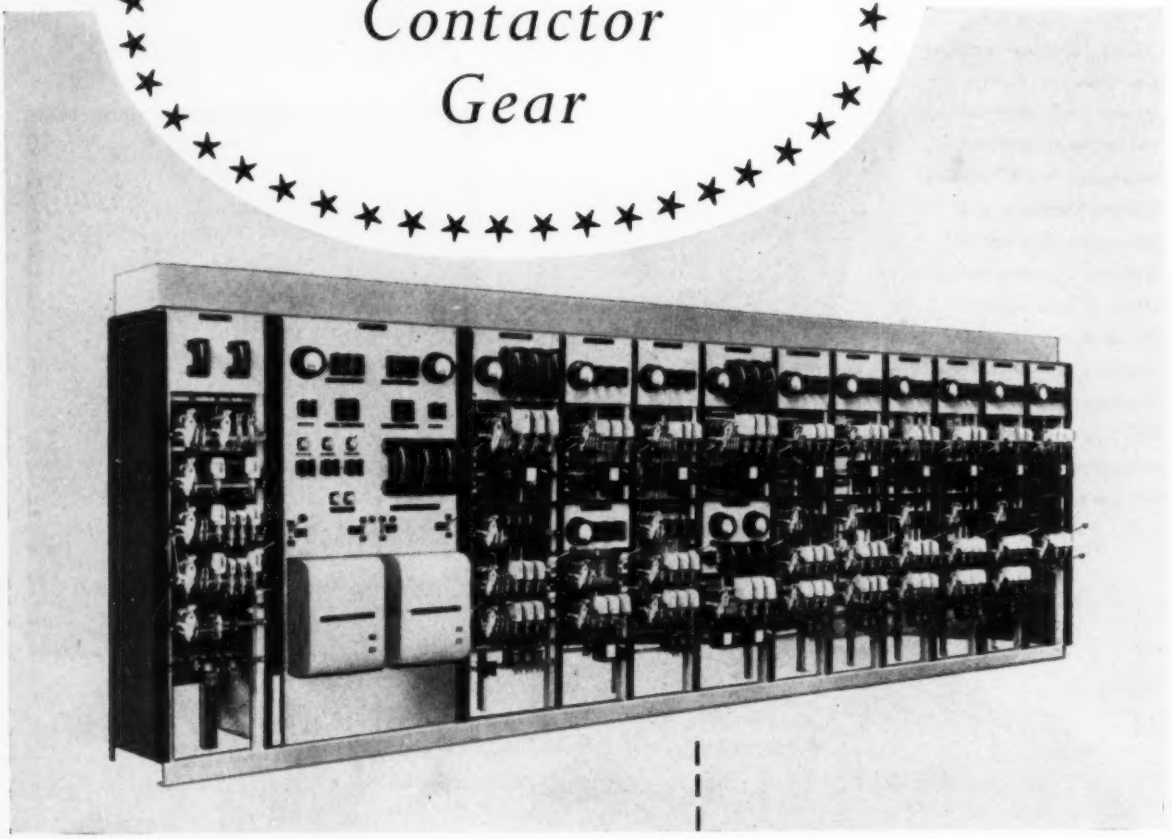

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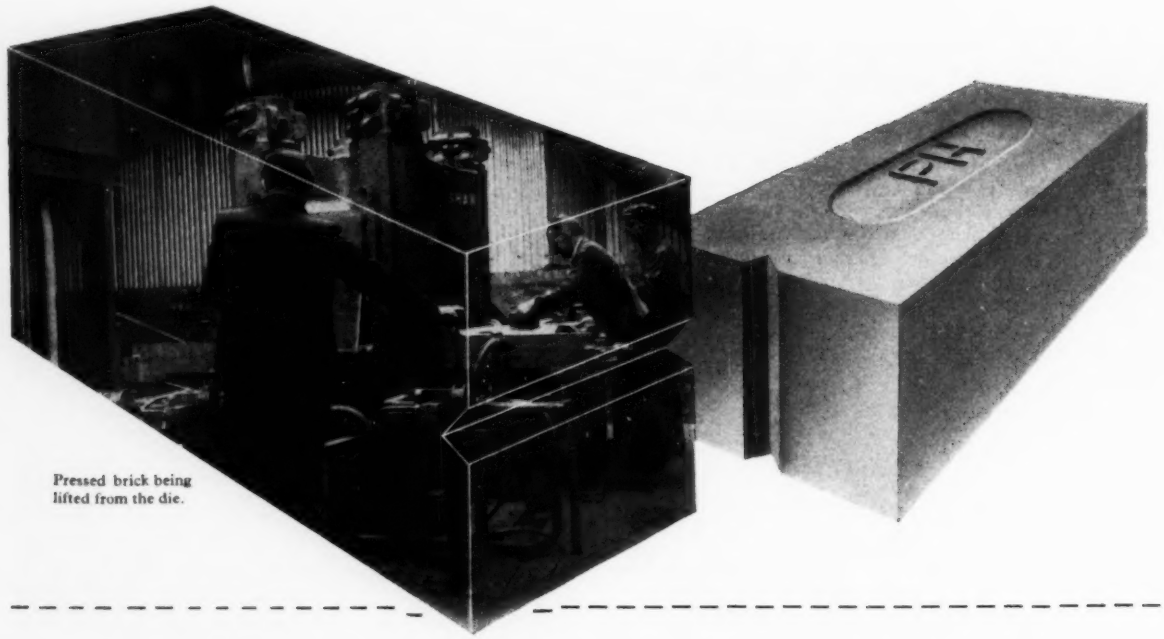

Pressed brick being lifted from the die.

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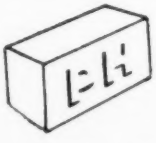

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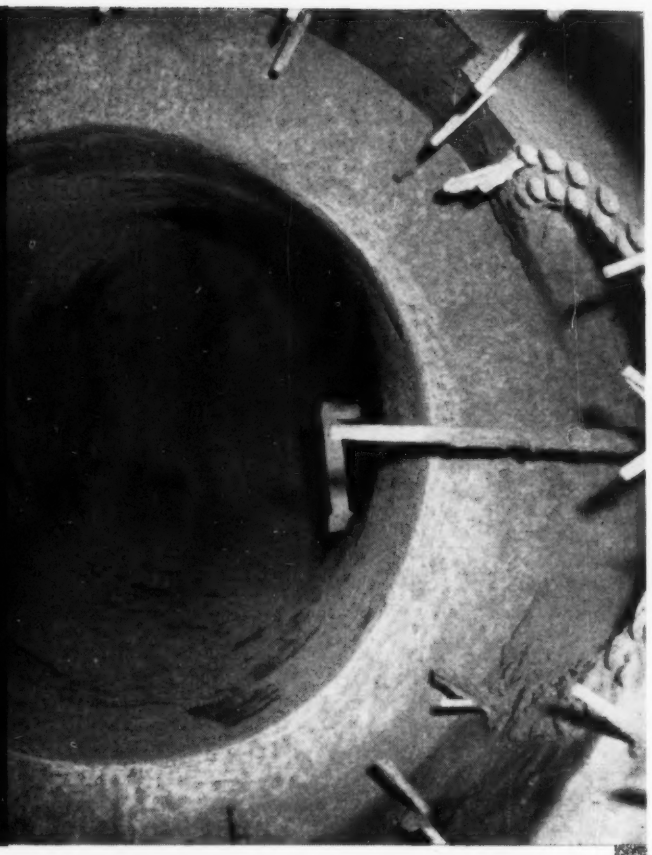

Bustle main of Queen Victoria Blast Furnace showing 'gunned' lining in Tri-Mor Dense 'Guncrete'. (Inside diameter of shell 5 feet. Thickness of 'Guncrete' lining 9 inches).
Photograph by courtesy of the Appleby-Frodingham Steel Co. (Branch of the United Steel Companies Ltd.).

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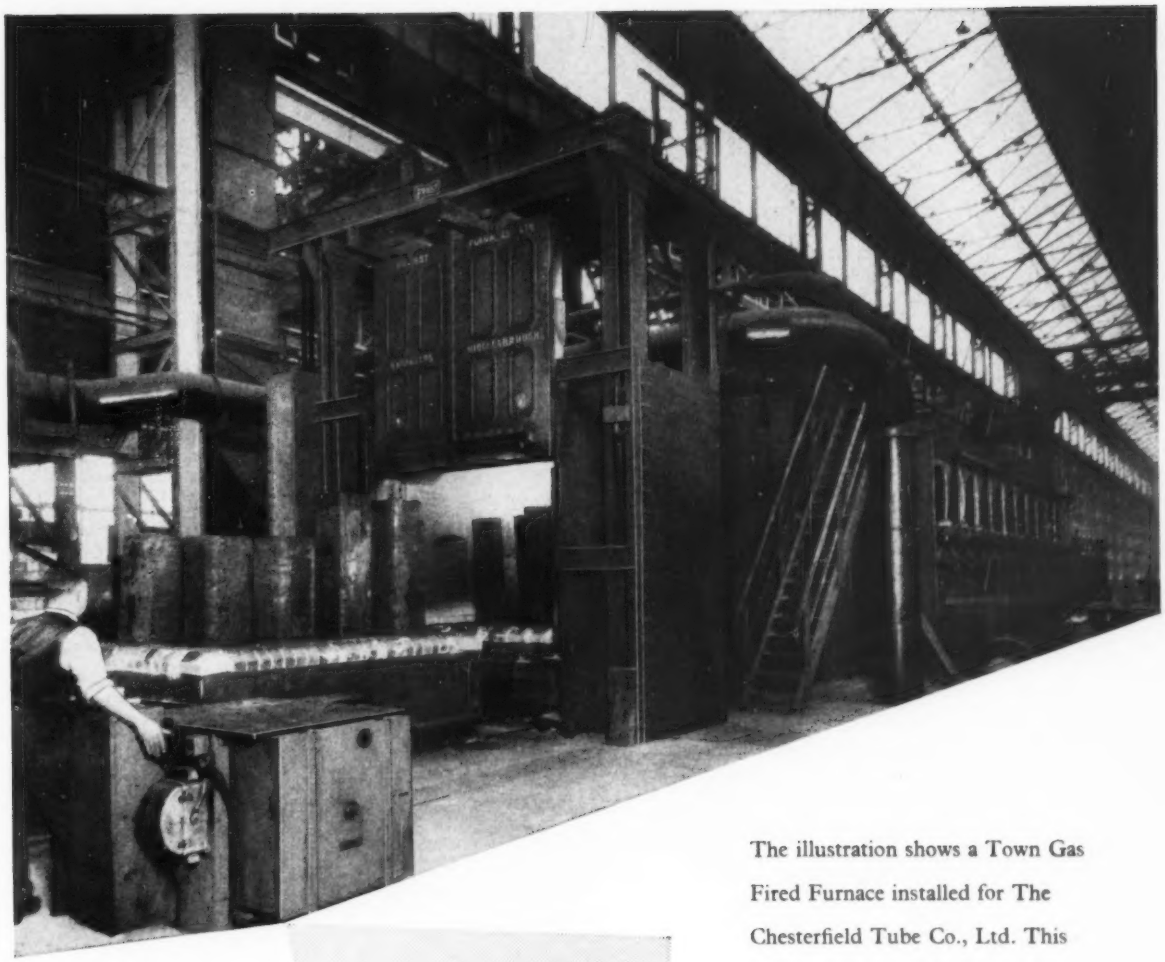

The illustration shows a Town Gas Fired Furnace installed for The Chesterfield Tube Co., Ltd. This unit is for heating billets prior to piercing and is also suitable for heat treating miscellaneous items in the soaking section.

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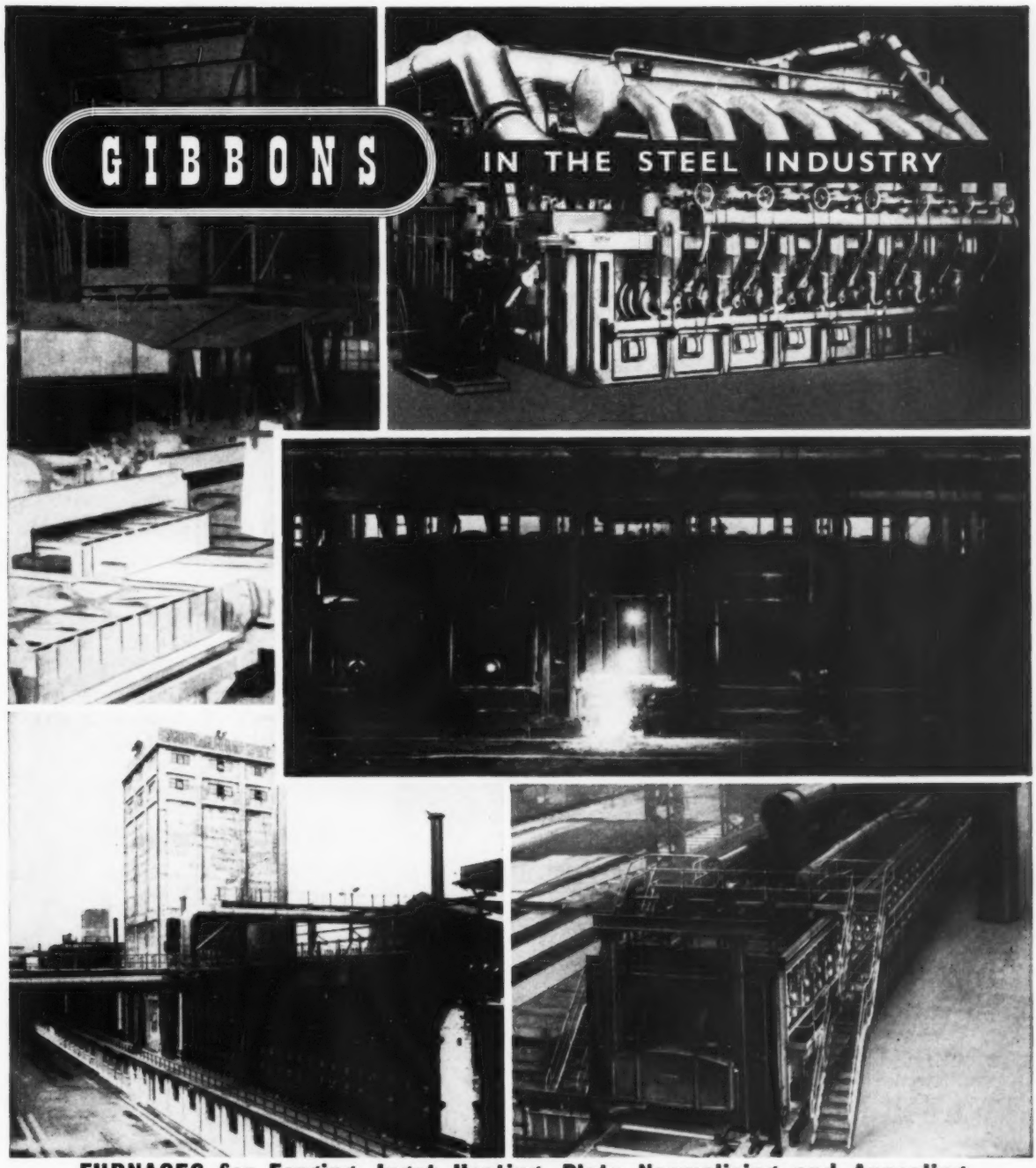

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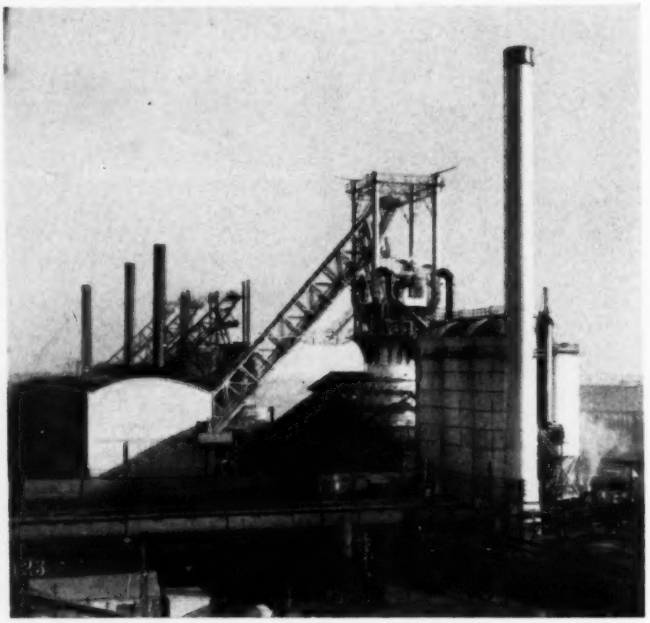

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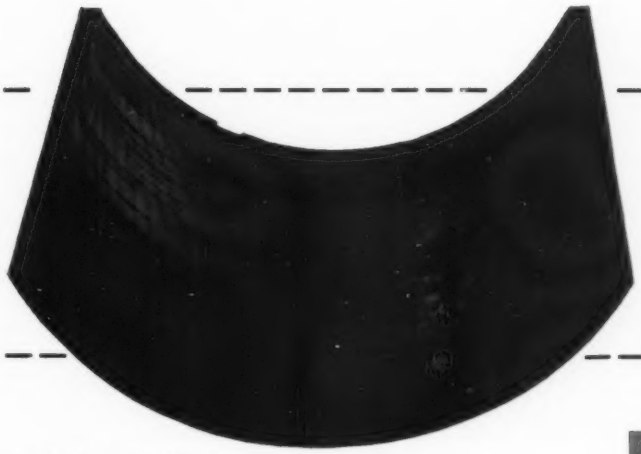

The bearing illustrated was removed from the bottom drive side of the above mill after rolling 126,000 tons of finished steel and would have continued for a further calculated 150,000 tons but for slight damage caused due to roll breakage. This performance was achieved despite high scale conditions which occurs in this position. In other positions up to 600,000 tons have been obtained.

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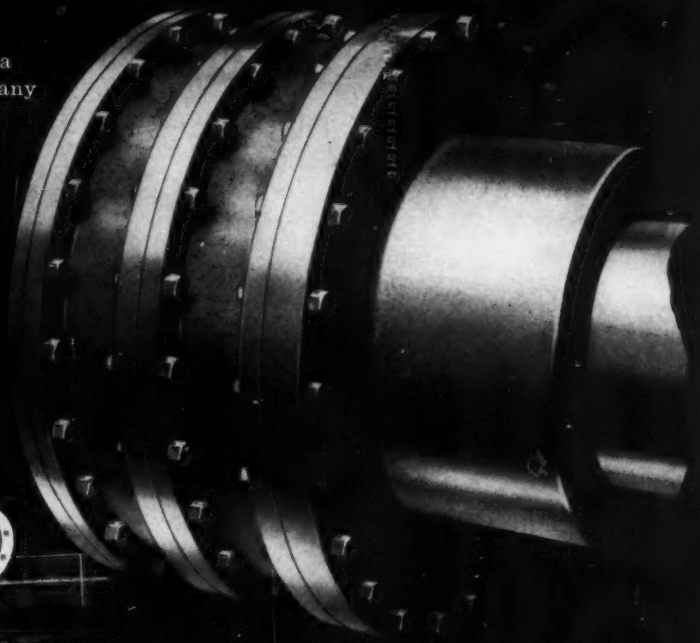

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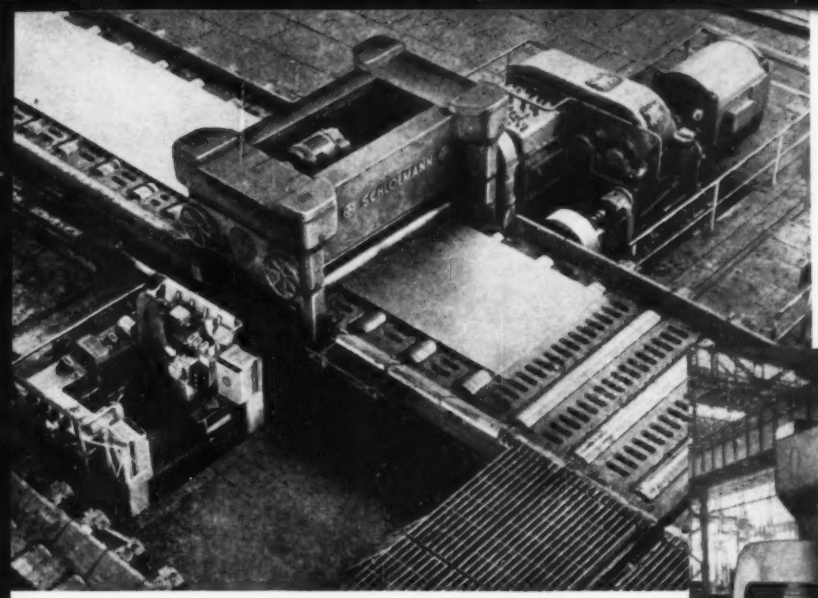

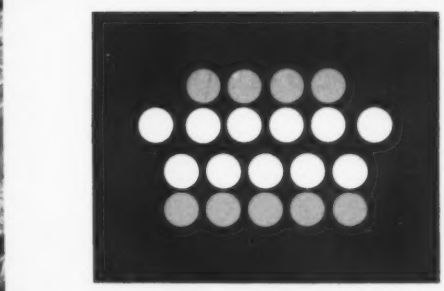

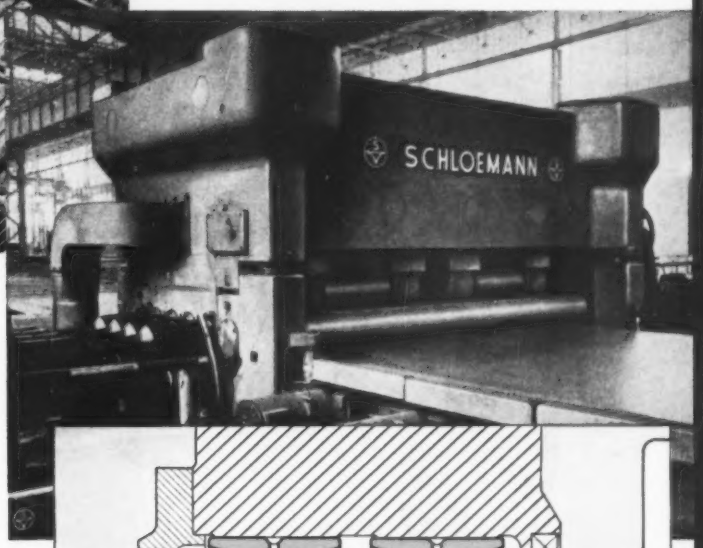

On a SCHLOEMANN hot-sheet leveller

This machine was built by SCHLOEMANN A.G. of Dusseldorf, for Deutsche Bergwerks and Huetten A.G.

The small diagram at the top shows the arrangement of the back-up rolls (in colour) and the pinch rolls (in white).

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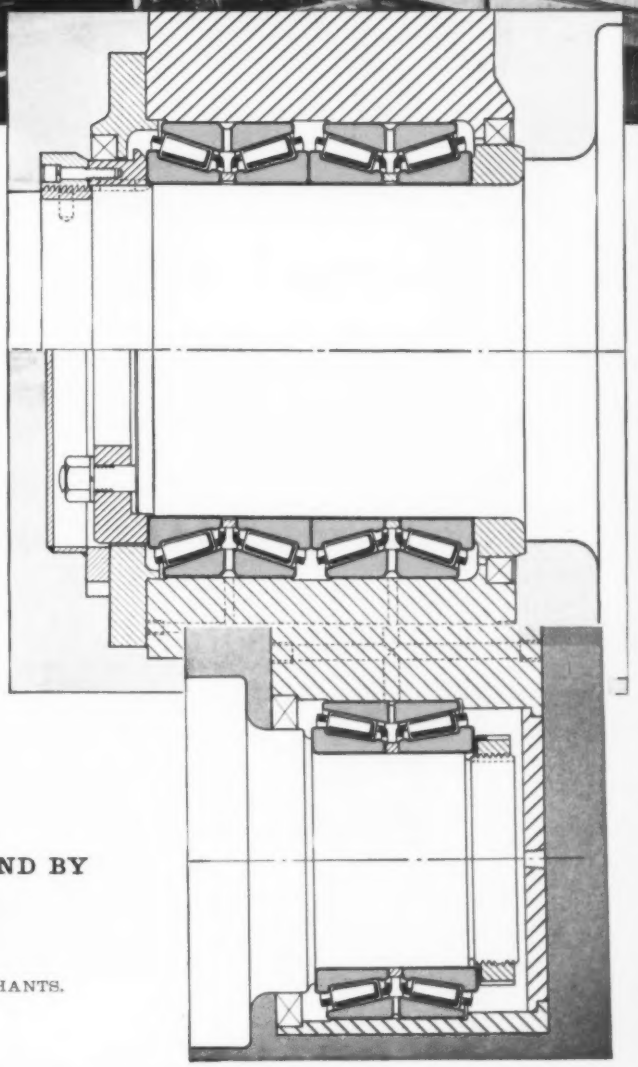
Messrs. SCHLOEMANN have built several of these sheet levellers, both the hot and cold types, equipped with Timken tapered-roller bearings.



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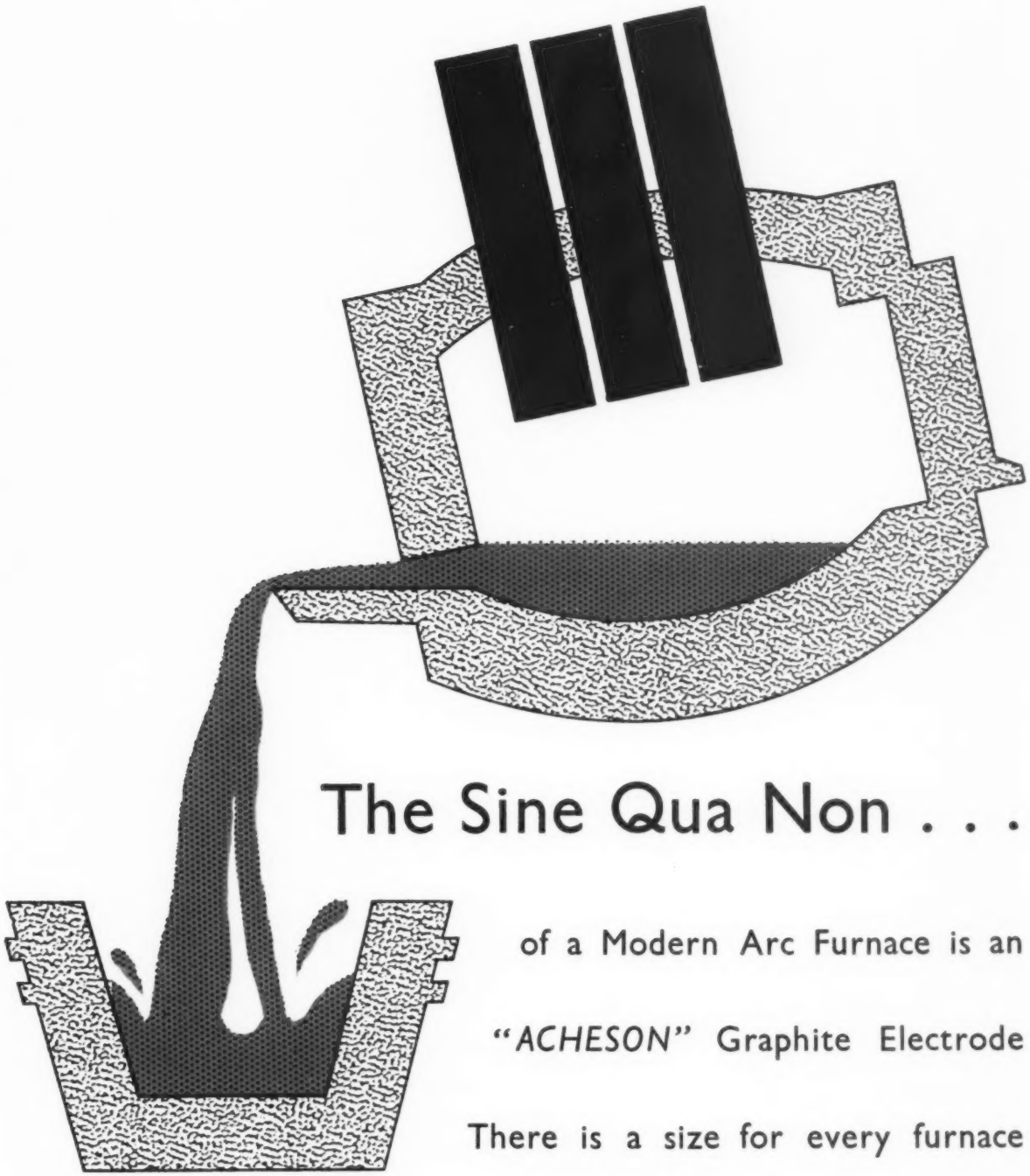

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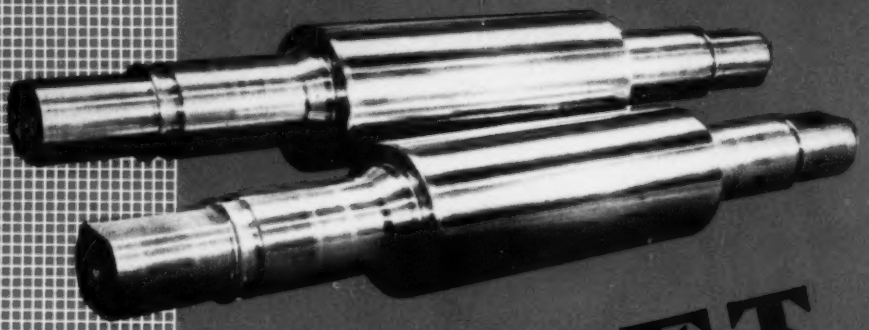

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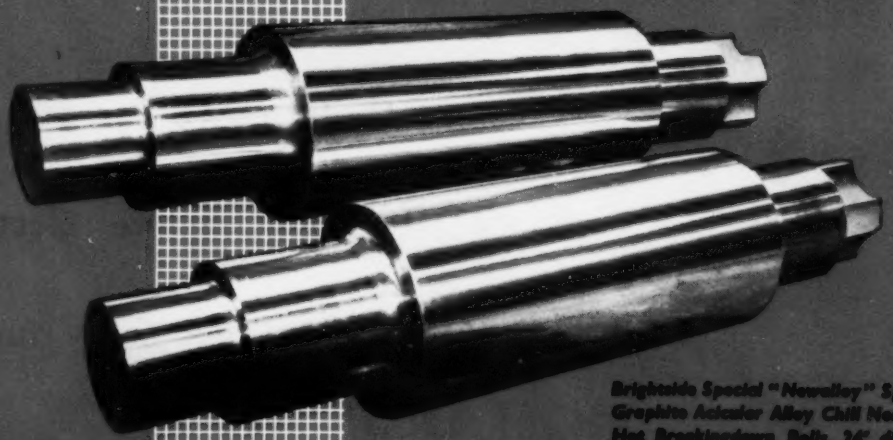

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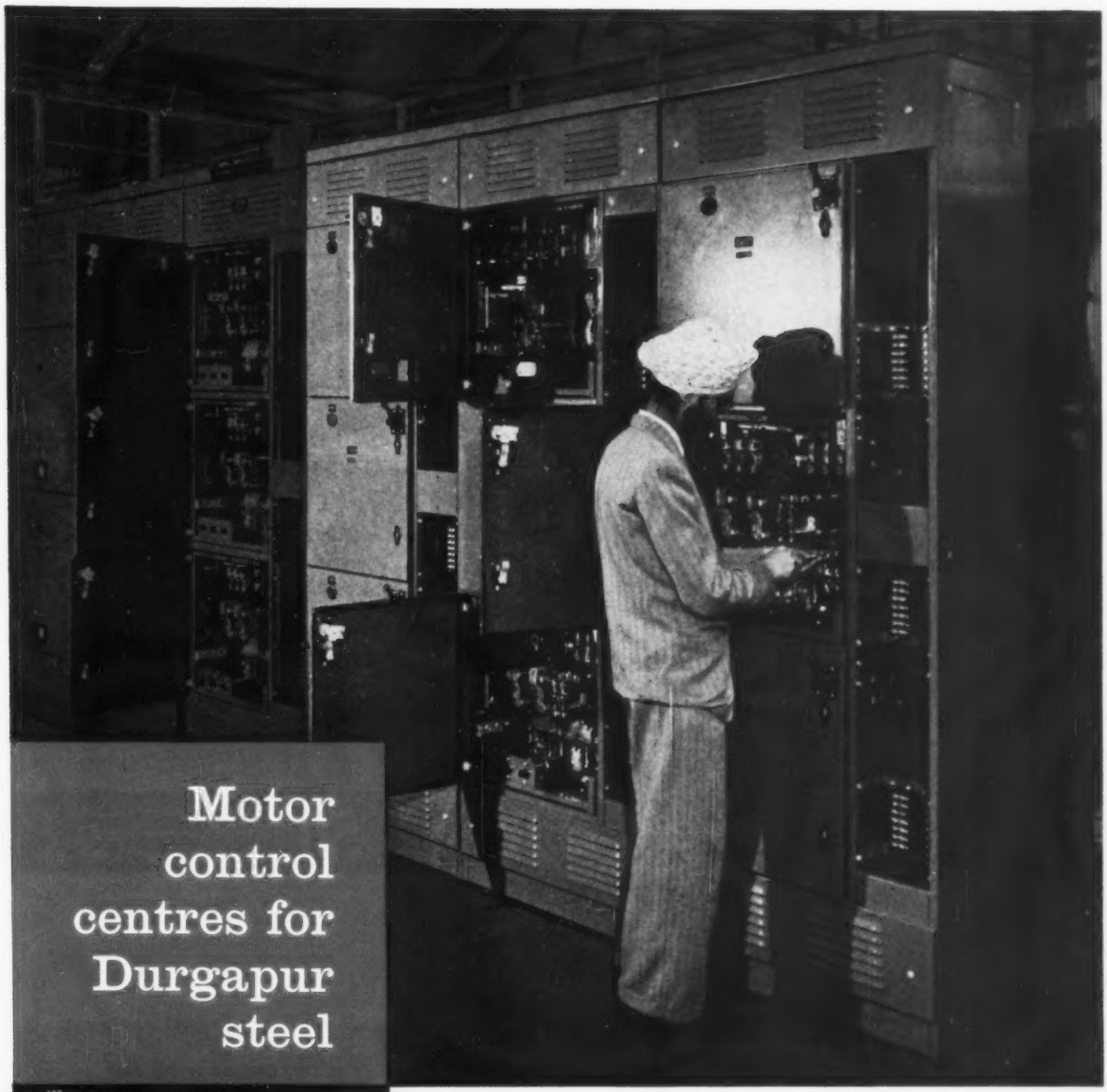

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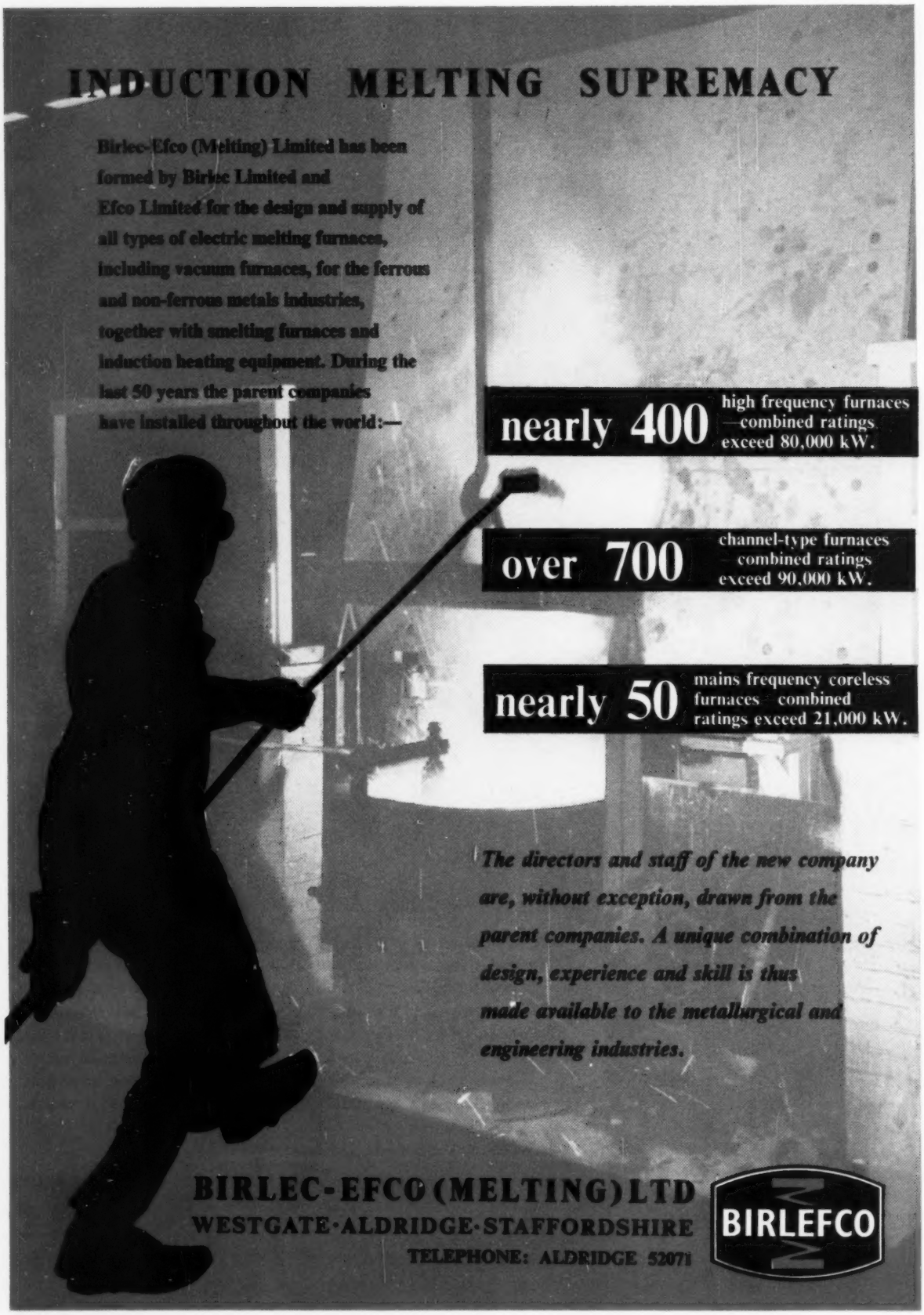
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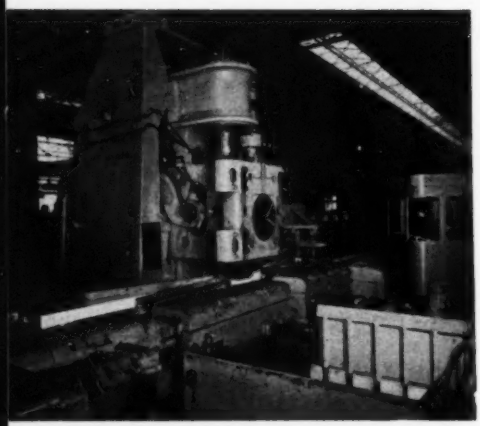
The Blooming and Slabbing Mill in action at Lackenby.

DAVY-UNITED AT DORMAN LONG



The 1,350 ton Hot Bloom and Slab Shear in operation.

The new Davy-United 52″ × 112″ Reversing Blooming and Slabbing Mill now in production in the Lackenby Works of Dorman Long (Steel) Ltd., is the largest of its type so far installed in Britain. It forms the primary unit of a new plant for producing universal beams which Dorman Long are now bringing into production.

Driven by twin 4,000 h.p. motors, each capable of developing up to 12,000 h.p. on peak loads, the mill is capable of rolling ingots weighing up to 20 tons. It was supplied along with a 1,350 ton hydraulic Hot Bloom and Slab Shear and all necessary handling, transfer and auxiliary equipment.

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I. P. BARDIN

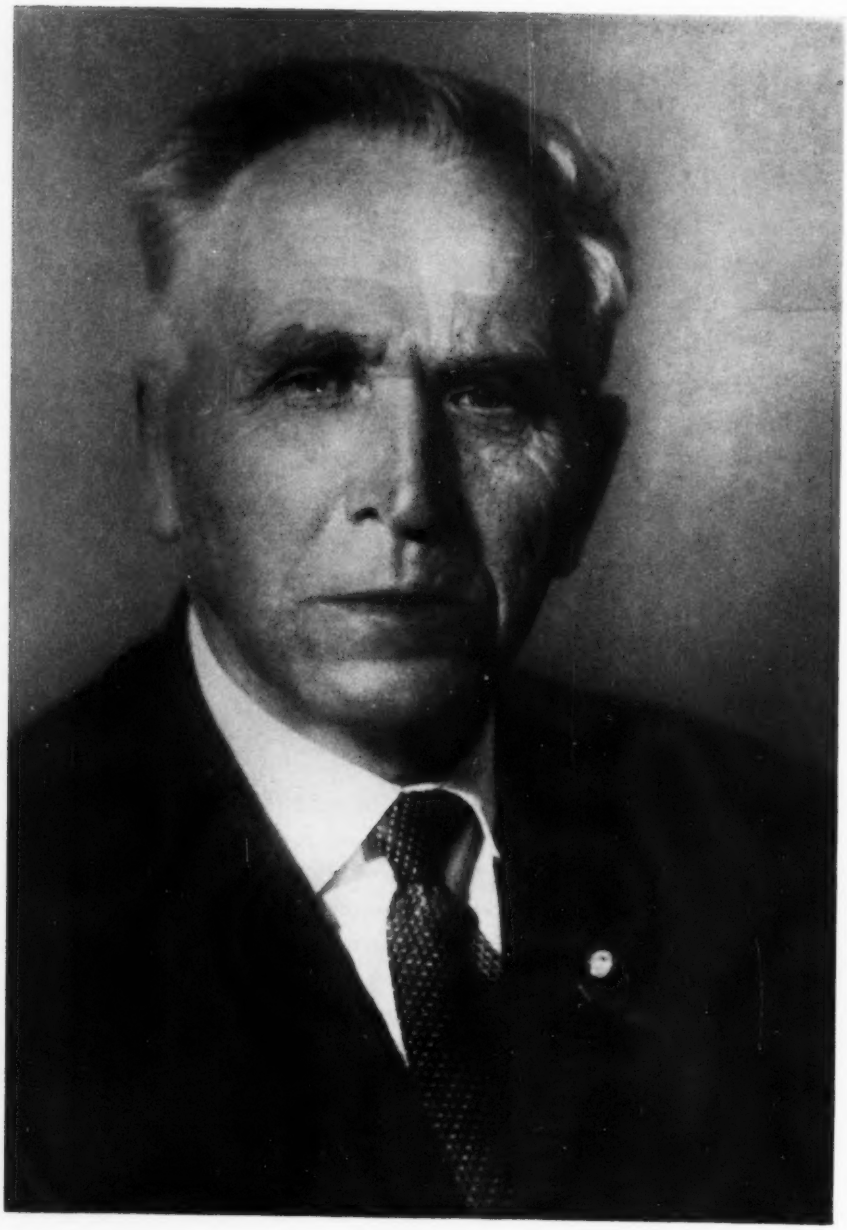
IVAN PAVLOVICH BARDIN was born in Russia in 1882. He attended first a town trade school and later an agricultural school and institute. However, his early interest in agriculture gave way to a study of chemistry, and he entered the chemical division of the Kiev Polytechnic Institute, where, for a time, he worked with Professor V. P. Izhevskii in developing an early form of electric furnace.

He graduated from the Institute as an engineer technologist, and as he could not find a suitable opening in the Russian metallurgical industry, he went to the USA where he gained experience of US industrial techniques. But he could not settle, and when his health failed he returned to Russia, where he worked with a blast-furnace expert, M. K. Kurako.

After the Revolution the new Soviet government concentrated on rebuilding the metallurgical industry, although in spite of the construction of 100-ton open-hearth furnaces and renovation of blast-furnaces built by Professor Bardin in southern Russia, the country's steel production in 1929 only equalled the 1913 level. To speed development, large steel and coal combines were planned, and Professor Bardin was technical manager of the construction of one of the first of these at Kuznetsk in Siberia in 1929.

Professor Bardin was elected member of the Soviet Academy of Sciences in 1932, and since 1942 he has been a vice-president and director of the A. A. Baykov Institute of Metallurgy. He is also head of the Central Iron and Steel Scientific Research Institute. He has long advocated mechanization in the iron and steel industry leading to full automation, although he has insisted that this must be matched by improved metal quality. He was twice awarded a Stalin prize, first for his work on the use of oxygen in open-hearth steel-making, and later for his war-time development of rail steels. He has also done considerable research into continuous casting techniques, for which he received a Lenin prize, and into new methods of pig-iron manufacture.

In 1953 Academician Bardin was elected an honorary member of the Hungarian Academy of Sciences and he is also an honorary member of the Rumanian and Czechoslovakian Academies. Last year he was re-elected a deputy of the Supreme Soviet.



Academician I. P. Bardin

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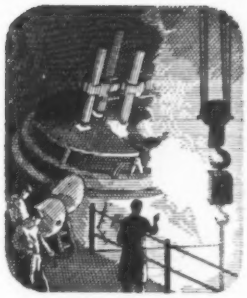

Continuous casting of steel in the USSR

By M. S. Boichenko, V. S. Rutes, D. P. Evteev, and B. N. Katomin

SYNOPSIS

A brief description of the characteristics of continuous-casting installations in the Soviet steel industry is given. The development of the design of the basic units of continuous casting-machines: (*a*) pouring equipment; (*b*) mould; (*c*) secondary cooling is described. Basic factors of the continuous casting of steel, quality of the cast semi-product and of the finished product, heat exchange and solidification of the steel under continuous-casting conditions are all considered. Technical and economic factors and the outlook for the continuous-casting process in the steel industry and research and development problems are discussed. 1655

DEVELOPMENT of the continuous casting of steel in the USSR has evolved in various directions in the last 10–15 years. The difference in emphasis is to be found mainly in the position of the cast slab or billet (i.e. whether vertical or inclined), in the method of withdrawal (i.e. whether continuous or semi-continuous), and also in the relationship between the shell of the casting and the mould wall (i.e. with or without sliding between the casting skin and the mould wall). The main tendency is towards the casting of metal into a vertical, water-cooled mould with continuous withdrawal of the cast product.

BRIEF DESCRIPTION OF INSTALLATIONS FOR THE CONTINUOUS CASTING OF STEEL

There are at present in the USSR several vertical installations for the continuous casting of steel. The various research and development projects relating to the process have been carried out by the Central Scientific Research Institute of Ferrous Metallurgy (TsNIIChM), together with plant operators, and the design, research, and study institutes (Gipromez, Stal'proyekt, Giprostal', etc.). Five such installations exist:

(1) The TsNIIChM pilot plant
(2) The semi-commercial installation at the Krasny Oktyabr' (Red October) works
(3) The pilot plant at the Kirov works in Leningrad
(4) The NTMZ (Novo Tula) semi-commercial installation
(5) The Krasnoye Sormovo production plant.

The work at TsNIIChM was begun in 1944 on an experimental, semi-continuous casting machine (Fig. 1). This machine was supplied with metal from a 1·5-ton arc furnace. The maximum length of the cast billet was 3 m. Metal from a stoppered ladle was poured into the mould through a special pouring device consisting of a trumpet, a short covered spout, and a stopper nozzle. Sections of various shapes and dimensions were experimentally cast: 100–280 mm (4–11 in.) diameter rounds, 100 mm × 100 mm (4 in. × 4 in.) to 300 mm × 300 mm (12 in. × 12 in.) squares, and rectangles ranging from 100–200 mm (4–8 in.) thick and 200–800 mm (8–32 in.) wide.

This experimental work made it possible to determine optimum conditions for casting different qualities of carbon and special steels and to develop and test designs for the individual parts of the machine, especially for the mould.

In 1951, the first semi-commercial semi-continuous casting plant was started up at the Krasny Oktyabr' works in Stalingrad for casting 150 mm × 600 mm (6 in. × 24 in.) and 175 mm × 300 mm (7 in. × 12 in.) slabs of 18–8 titanium-stabilized stainless steel. The installation consists of two machines with screw-withdrawal mechanism; it can produce billets up to 7 m (22 ft 9 in.) long (Fig 2). Metal from a normal ladle is fed into a stoppered tundish and thence into the mould, which is of the reciprocating type.

Work has now begun on the reconstruction of the plant so that it will be capable of casting slabs up to 10 m (32 ft 6 in.) long from a 10-ton ladle.

An experimental semi-continuous casting machine similar to that at the Krasny Oktyabr' works was installed at the Kirov works in Leningrad in 1953. This machine was used for producing carbon-steel square blooms 200 mm × 200 mm (8 in. × 8 in.) and 350 mm × 350 mm (14 in. × 14 in.). The metal was teemed from a 5-ton ladle through a stoppered tundish.

At the end of 1953, a pilot plant for the continuous casting of steel was put into operation at the Novo Tula works. This plant was designed to produce slabs up to 200 mm (8 in.) thick and 600 mm (24 in.) wide. The basic part of the machine, with an overall height of 22 m (71 ft 6 in.), is in a pit 19 m (61 ft 9 in.)

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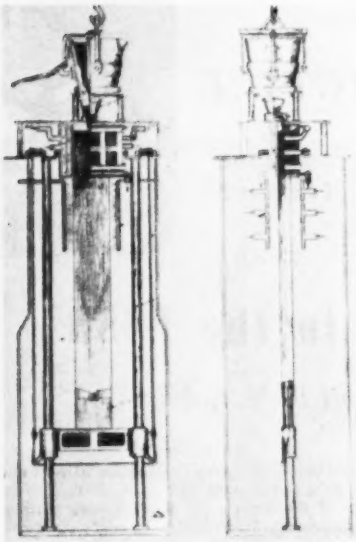


Fig. 1—Experimental plant at TsNIIChM for semi-continuous casting of steel

deep (Fig. 3). The steel is produced in a 10-ton experimental OH furnace, a 7-ton converter, and a 5-ton arc furnace and is poured from a stoppered ladle through a tundish. The mould is of the reciprocating type. The 7-m (22 ft 9 in.) long secondary-cooling section is of the nozzle-roller type.

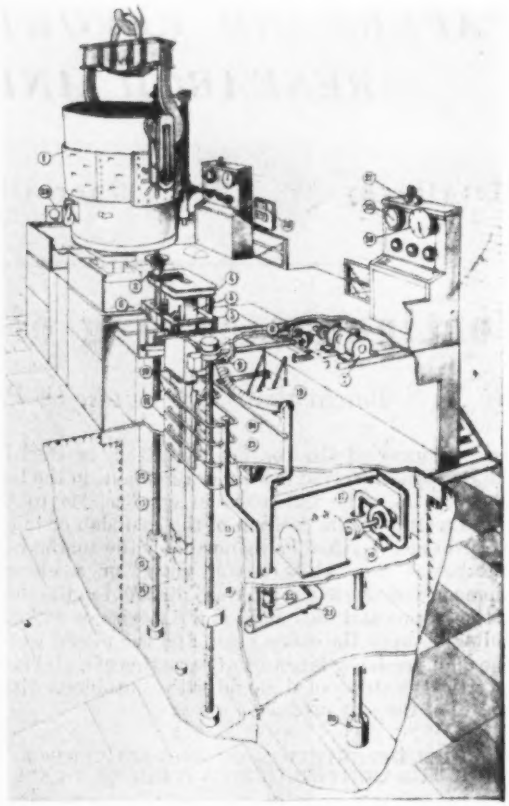
Development work was carried out on this installation during 1954–1956 for the casting of killed and rimming carbon steel, low-alloy, and transformer-steel slabs 150 mm × 475 mm (6 in. × 19 in.). The cast slabs were rolled into sheets of various thicknesses and qualities. In 1957, the machine was converted to a two-strand type for the production of 200 mm × 200 mm (8 in. × 8 in.) squares. In addition to the types of steel mentioned above, carbon tool steels were also cast using a twin-stoppered tundish. The continuously cast squares were rolled into rounds, angles, and channels.

The plant works three shifts and apart from its experimental programme, there is also a production programme for about 1 000 tons of good cast product a month.

The first industrial installation in the USSR for the continuous casting of steel began operation in May, 1955 at the Krasnoye Sormovo works. It was designed for the continuous casting of 175 mm × 420 mm (7 in. × 16½ in.) slabs. The installation consists of two machines which receive metal from a 50-ton stoppered ladle (Fig. 4). Overall height of this machine is 16·8 m (54 ft 7 in.). The pouring platform is 3·8 m (12 ft 4 in.) above shop-floor level. The tundish divides the supply of metal to feed two stationary moulds. The nozzle-roller type secondary-cooling section is 4·5 m (14 ft 7 in.) long.

The quality mostly cast is medium-carbon killed steel. Casting trials were also undertaken with rimming and low-carbon steels. The cast product was rolled mainly into sheet. Rolling trials of the continuously cast product were also carried out in the section mills. The plant works three shifts and casts about 3 500–4 000 tons of steel per month. Development work is also in progress to perfect the design of the basic parts of the machine. Construction of a second twin-strand machine has now begun. When this machine goes into service in 1959, the shop will have gone over entirely to continuous casting.

Since the plant began operating, 104 000 tons of good slab have been cast and rolled into sheet.



1 Pouring ladle
2 Tundish
3 Mould
4 Manifold for mould water cooling
5 Mould suspension
6 Platform
7 Motor for reciprocating mechanism
8 Reducing gear for slab extractor
9 Reducing gear for reciprocating mechanism
10 Water outlets
11 Secondary cooling
12 Slab
13 Dummy billet
14 Transverse beam
15 Worm drives for withdrawing slab
16 Floating nuts
17 Pump motor
18 Centrifugal pump, pumping water into mould and front secondary cooling
19 Flexible pipe for supplying water to mould
20 Water intake from tank
21 Water supply from mains
22 Reversing valve
23 Water feed to side secondary cooling
24 Water feed to front secondary cooling
25 Meter showing amount of water used in mould cooling
26 Indicator showing length of slab
27 Bell on control apparatus indicating end of pour
28 Recorder showing temperature of the water in the mould cooling system
29 Automatic recorder indicating the casting speed

The diagram does not show the following:
Controls regulating the withdrawal mechanism
Meters concerned with the secondary cooling
Radioactive level indicator, and other instruments

Fig. 2—The Krasny Oktyabr' (Red October) works' semi-continuous casting machine

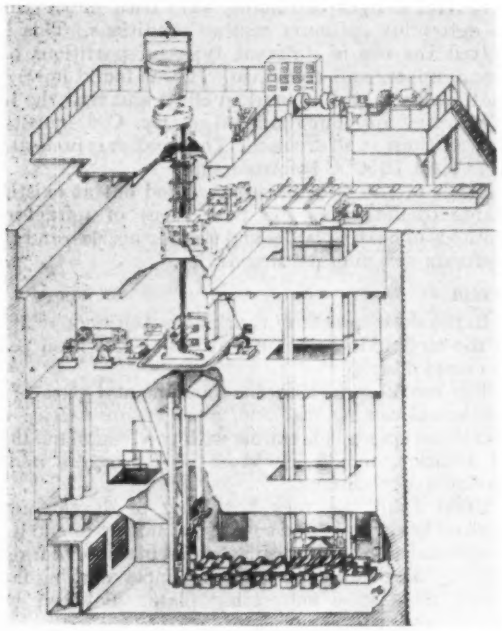


Fig. 3—Semi-commercial continuous-casting installation at Nova Tula

DEVELOPMENT OF THE BASIC PARTS OF THE CONTINUOUS-CASTING PLANT

A machine for the continuous casting of steel consists of:

(i) The pouring device through which the molten metal is fed to the mould

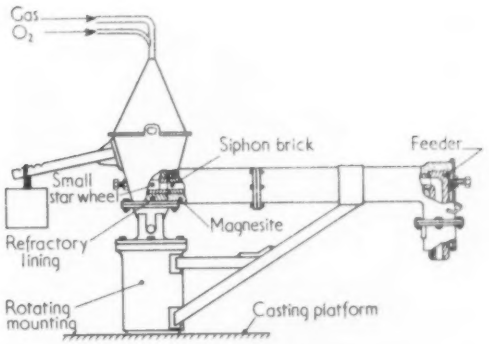


Fig. 5—Pouring device

(ii) The mould, to form the shape of the casting
(iii) The secondary cooling zone, where further cooling takes place and the metal freezes completely throughout its entire cross-sectional area
(iv) The withdrawal mechanism
(v) The cutting mechanism
(vi) The device for removing and transporting the casting.

The mechanisms for withdrawing, cutting, and removing the cast product may vary in design, but this does not affect the process of continuous casting. The main requirement is reliability. The basic parts of the plant—the pouring device, the mould, and the secondary cooling equipment—are quite a different matter. The quality of the continuously cast product and the success of the processes as a whole depend to a great extent on the design of these latter units.

Pouring device

Normal stoppered ladles are used in all the plants

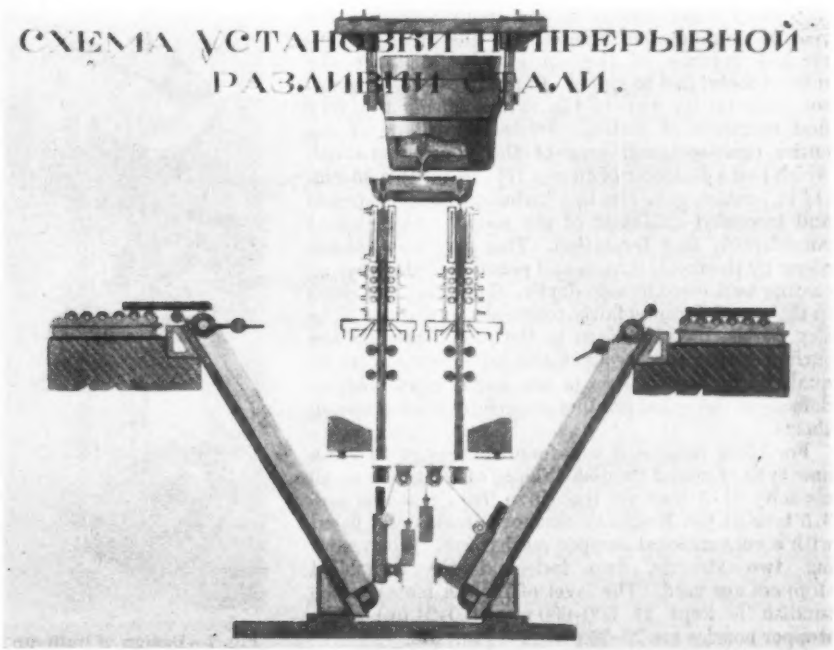


Fig. 4—Commercial continuous-casting plant at Krasnoye Sormovo

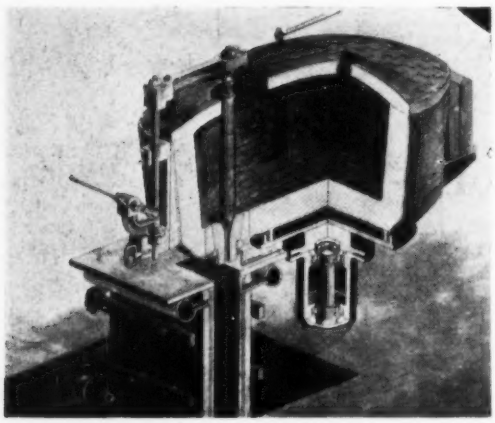


Fig. 6—Section through new type of closed tundish

operating in the USSR. Molten steel from the main ladle is passed through a tundish into the mould. The basic requirements for the pouring device are that it must ensure that metal is fed to the mould at a given rate, that the pouring stream must be well ordered so as to minimize splash, and that it must be possible, in an emergency, to cut off metal supply to the mould without delay.

During the early stages of development, the pouring device consisted of a closed spout, a trumpet, and a special stopper nozzle. This pouring device (Fig. 5) was of simple design and convenient to operate.

Research, however, showed that the use of this type of pouring device adversely affected the quality of both the cast product and the final rolled product. The chief disadvantage of the spout was that the risk of non-metallic inclusions in the steel was increased because of the considerable distance the molten metal had to travel. In many cases, the metal solidified on its way to the mould during the very first moments of casting. Incomplete filling of the entire cross-sectional area of the pouring channel, which had a diameter of 40 mm ($1\frac{37}{64}$ in.) with a 35-mm ($1\frac{3}{8}$ in.) outlet, gave rise to a turbulent pouring stream and increased oxidation of the metal, which caused considerable slag formation. This slag was carried along by the metal stream and penetrated the freezing casting to a considerable depth. Some slag remained in the metal, forming fairly coarse slag inclusions. The slag at the metal surface in the mould reaches the surface of the cast product and adversely affects its quality. Slag inclusions in the metal cause various defects in the rolled product, especially laminations in sheets.

For these reasons it was found necessary to use a new type of closed tundish (Fig. 6) of relatively small capacity (1·5 tons on the Novo Tula machine and 3·5 tons at the Krasnoye Sormovo works) and fitted with a conventional stopper mechanism. When casting two strands, two independently controlled stoppers are used. The level of molten metal in the tundish is kept at 500–600 mm (20–24 in.). The stopper nozzles are 25–35 mm (1–$1\frac{3}{8}$ in.) dia.

Several designs of tundish were tried in an effort to determine optimum casting conditions. This involved the use of different types of partitions e.g. lower, upper, and combined. It was found however that their use had no marked effect and that the life of the refractory lining suffered greatly. Consequently, no partitions at all are used. The tundish is preheated to at least 1 100° C before casting.

Trials are at present being carried out at existing plants to determine the best types of refractory, methods of heating ladles and stopper nozzles, and the optimum design of pouring device.

Mould

In the development of continuous-casting machines in the steel industry, much attention has been paid to mould design.

The mould, which is the fundamental part of a continuous-casting machine, must ensure casting at maximum speeds compatible with good metal quality. In addition, mould life must be reasonable under production conditions.

Right from the very beginning of development work on heavy slabs and squares, a built-up mould was used, consisting of four walls secured in a special frame (Fig. 7). Each wall consists of a copper working face bolted to a steel supporting plate. Between the copper and the steel plates are channels through which cooling water circulates. The speed of the water through the channels is 6–8 m (19 ft 6 in. to 26 ft) per second. Overall length of the mould is 1·5 m (4 ft 11 in.).

Temperature measurements in the mould walls made

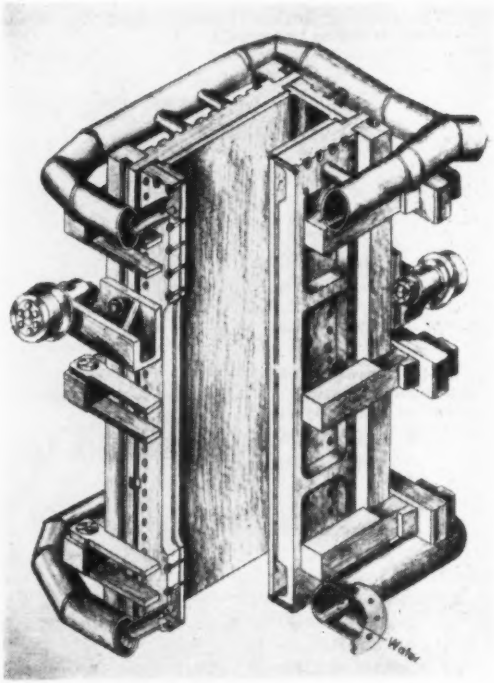


Fig. 7—Design of built-up mould for casting slabs

during casting, showed that there are steep temperature gradients throughout the thickness, length, and breadth of the walls. These gradients are especially marked in the upper zone of the mould. The thermal stresses arising in the mould walls exceed, by several times, the yield point of copper. Consequently, irrespective of wall thickness and the method of securing the walls, a certain amount of permanent set does occur in the latter. With thin walls only about 5 mm ($\frac{13}{64}$ in.) thick, permanent set exists mainly in the form of transverse waviness. Such waviness is extremely undesirable, especially in the casting of wide slabs. Trials involving the casting of slabs 150 mm × 475 mm (6 in. × 19 in.) in a mould with 5 mm ($\frac{13}{64}$ in.) thick walls showed that, when transverse waviness in the wide walls reached 1 mm ($\frac{3}{64}$ in.), surface cracks appeared in the slabs. The critical amount of waviness for wider slabs will be still less.

With a mould wall thickness of 10 mm ($\frac{25}{64}$ in.) and more, permanent set occurs mainly as transverse shrinkage of the copper plate. This finally has an adverse effect on the tightness of the wall joints at the corners of the moulds and weakens the union between the copper and steel plates.

The accumulation of permanent set in the mould walls during the operation of the mould means that, at some particular moment, these deformations will begin to exceed the critical limit and a gap will occur at the mould wall joints. The mould will then have to be replaced.

Moulds used at present normally have a copper face thickness of 12–18 mm ($\frac{15}{32}$–$\frac{23}{64}$ in.) as such moulds exhibit the least amount of transverse waviness and can be repaired several times by machining the copper working faces of the mould walls. Thus, mould life is improved and the consumption of copper per ton of steel cast is reduced.

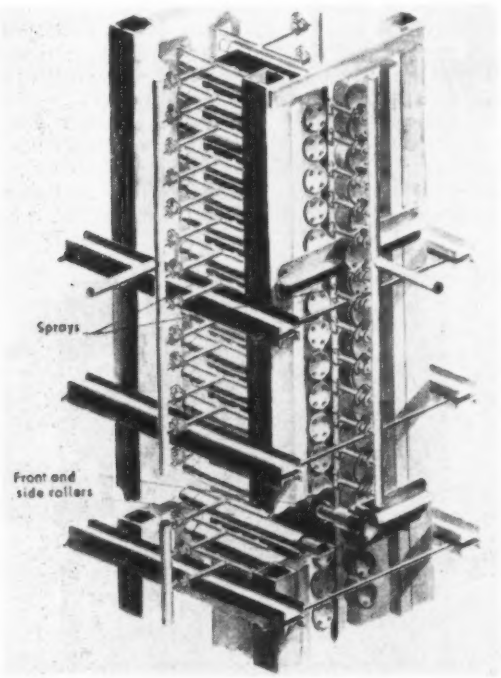


Fig. 8—Design of nozzle-roller secondary cooling

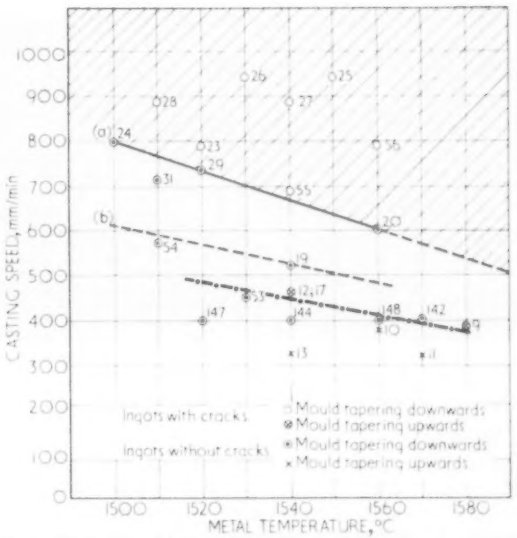


Fig. 9—Influence of liquid metal temperature and casting speed on formation of external cracks

Average mould life in an industrial machine is 3 000–4 000 tons. Such a life is reasonable for continuous-casting machines with a productivity of the order of 100 000 tons annually but is inadequate for installations of greater productivity. It is, therefore, essential to direct research and development work toward the construction of moulds with longer lives.

Secondary cooling

Development work on a system of secondary cooling of the cast product has been carried out for several years mainly on the semi-commercial plant at Novo Tula.

In the early stages of this work, the slab was severely quenched as it left the mould. The secondary cooling zone was relatively short—about 1 m (3 ft 3 in.). Water was sprayed on to the slabs from boxes with apertures. Water consumption exceeded 3 l./kg (0·27 gal/lb) of steel. Under these conditions, internal cracks were usually found in castings of various qualities (except those of the austenitic stainless variety). In developing a new system of secondary cooling, the severity of quenching was greatly reduced. Since the surface temperature of the slab did not now drop below 700–800° C, special support rollers are used to prevent deformation (convexity) of the slab faces by ferrostatic pressure (Fig. 8). Water is sprayed on to the surface of the casting by means of nozzles. The amount of water used is less than 1 l./kg of steel (0·09 gal/lb).

The basic requirement of a secondary cooling system is uniformity of cooling throughout the axial zone of freezing. Support rollers must also be installed the entire length of the cooling zone.

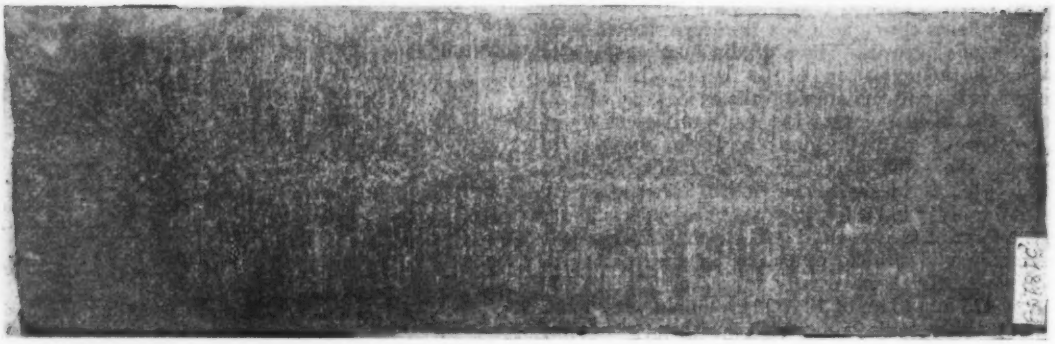


Fig. 10—Section of a slab 150 mm × 475 mm (6 in. × 19 in.) of a medium-carbon steel

By means of a nozzle-roller type of secondary cooling with less severe quenching and with suitable length of the secondary cooling zone, it was possible almost entirely to eliminate internal cracks in the slabs, with the exception of cracks associated with local deformation of the section (where there is a tendency to ovality—a sort of squashing effect). These defects usually originate in the mould and develop further in the secondary cooling zone as a result of non-uniform cooling.

If the secondary cooling zone is too short (i.e. when the mould ends outside this zone) internal cracks can occur as a result of overheating of the slab surface. The secondary cooling zone, therefore, consists of a number of sections which can be switched on or off as required so that the correct relationship between the length of the freezing portion of the slab and the length of the secondary cooling zone itself can always be maintained.

When casting squares on the Novo Tula machine, using speeds above 0·8 m (31 in.) per minute, freezing of the casting is completed below the first set of pinch rolls. In such cases, castings with a molten core are subjected to a certain amount of compression in the pinch rolls. The amount of compression is slight—of the order of 3–4%—but it does, nevertheless, adversely affect the quality of the continuously cast product, giving rise to internal cracks at the faces parallel to the axes of the rolls. This fact must therefore be taken into account when designing a continuous-casting machine so that the pinch rolls are not located in the secondary cooling zone.

Our present task is to concentrate our efforts on the determination of rational cooling conditions and on creating more uniform cooling for the various qualities of steel.

Thus, vertical types of continuous-casting machines in the USSR have the following features:

(i) The metal is poured from a stoppered ladle
(ii) The metal is passed through a tundish into the mould and the metal feed is controlled by means of small stoppers
(iii) For casting rectangular and square products, built-up water-cooled moulds are used, consisting of four copper walls, the moulds tapering inwards towards the bottom. Mould length is up to 1·5 m (5 ft)
(iv) Both reciprocating and stationary moulds are used
(v) The level of metal in the mould is maintained constant (within limits of ± 50 mm (± 2 in.) with forced lubrication
(vi) The cooling rate of the casting leaving the mould is controlled to ensure uniform cooling
(vii) Continuous-casting machines are housed mainly below ground level, the machines being housed in special pits in the pouring bays. This arrangement makes it possible to install continuous-casting machines in existing melting shops and to utilize existing crane facilities, etc.

DETERMINING THE OPTIMUM OPERATIONAL CONDITIONS FOR THE CONTINUOUS CASTING OF STEEL

In order to obtain a high-grade product, the continuously cast billet or slab must have a sufficiently clean surface and a sound internal structure which will ensure the requisite mechanical properties. The main factors that determine the quality of the continuously cast product are the temperature of the molten steel, the casting speed, and uniform controlled cooling of the product leaving the mould.

One of the main requirements of the continuous casting of steel is that the surface of the molten metal

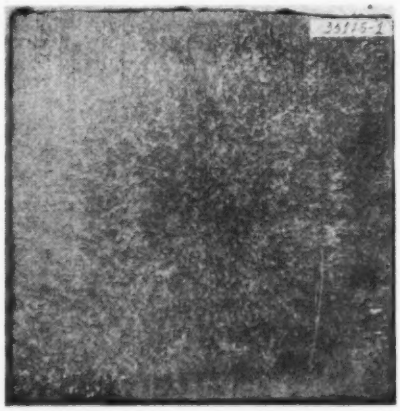


Fig. 11—Section of a square billet 200 mm × 200 mm (8 in. × 8 in.) of a medium-carbon steel

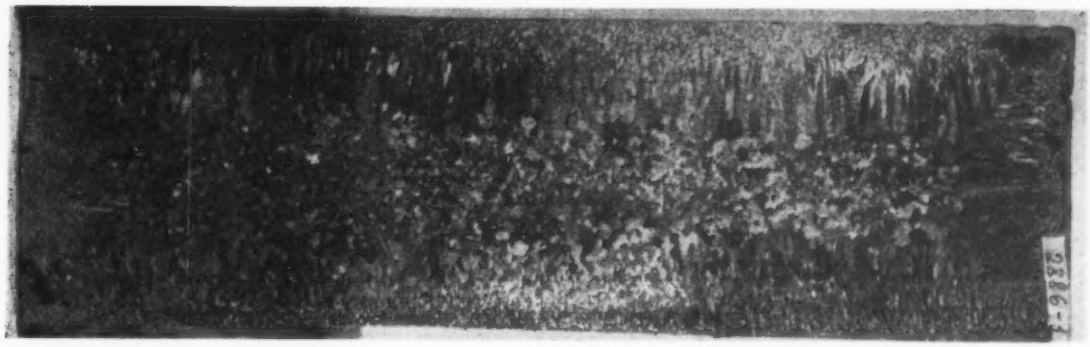


Fig. 12—Section of slab 150 mm × 475 mm (6 in. × 19 in.) of a transformer steel containing 4·5%Si

in the mould should be quite free from oxide films and skin, which adversely affect the surface quality of the continuously cast product and cause additional contamination of the steel with non-metallic inclusions.

When carbon, low-alloy, and transformer steels are continuously cast, the surface of the molten metal in the mould is kept clean by a suitable choice of metal temperature, lubricant, and casting speed. When metal temperature and casting speed are increased, the probability of oxide-film formation is reduced. It should be noted that the use of liquid paraffin also keeps the molten metal surface free from oxide film.

In the case of 18–8 titanium-stabilized stainless steel, a coarse oxidized skin is formed on the metal surface in the mould, even with high liquid-steel temperatures (up to 1 640° C) and high casting speeds (up to 1 200 mm/min, i.e. 48 in./min). This oxidized skin interlocks with the solidifying shell of the casting,

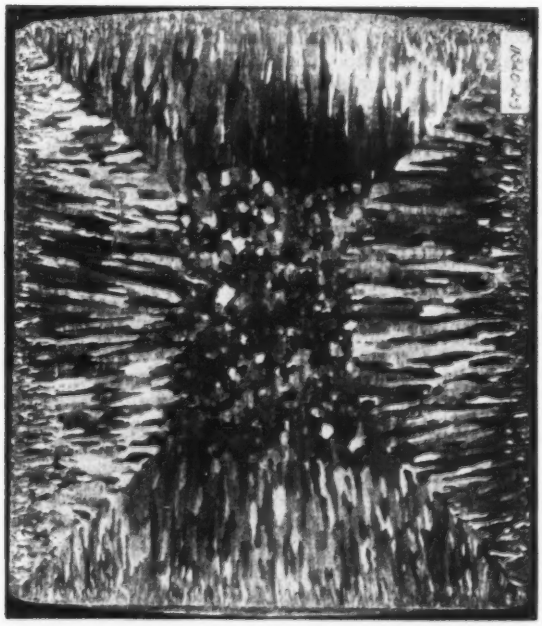


Fig. 13—Section of a square billet 200 mm × 200 mm (8 in. × 8 in.) of a transformer steel containing 4·5%Si

is drawn inward, and impairs the surface of the casting. In this case, to prevent the skin being drawn inward and to limit its growth, pieces of wooden board are used to cover the surface of the molten metal.

The determination of optimum casting conditions for each type of steel demands careful study of all the factors affecting the quality of the cast product, plant productivity, etc.

Much research has shown that an increase in liquid-steel temperature is associated with an improvement in the surface quality of the continuously cast product, Excessively high metal temperature, however, leads to the formation of external longitudinal cracks (Fig. 9). This in turn makes it necessary to lower the casting speed, which of necessity means a drop in productivity. Moreover, a high liquid-steel temperature causes considerable wear of the refractory linings, greater metal contamination, and increased central porosity with more internal transverse cracks.

Low metal temperature, adversely affecting surface quality, can give rise to freezing of the steel in the stopper nozzles of the tundish, which will bring the casting process to an end.

The influence of casting speed on the quality of the continuously cast product is similar to that of metal temperature. When the casting speed is raised, the slab or billet surface is improved but there is a greater risk of the formation of external longitudinal cracks (Fig. 9), and the development of central porosity and the number of internal transverse cracks is increased. A drop in casting speed improves the internal structure of the cast product but, at the same time, adversely affects the surface of the slab or billet and lowers the productivity of the plant.

Intensity and uniformity of cooling after the casting leaves the mould—in the secondary cooling zone—are of great importance in imparting a sound internal structure to the cast product. If considerable amounts of water (more than 3 l./kg, i.e. 0·27 gal/lb of steel) are used in the secondary cooling zone, there is a sudden drop in the surface temperature of the cast product. The occurrence of steep temperature gradients in the freezing layer of the casting gives rise to thermal stresses and internal cracks. Internal cracks are formed in the layer of solid metal adjacent to the crystallization front. Some of these cracks become

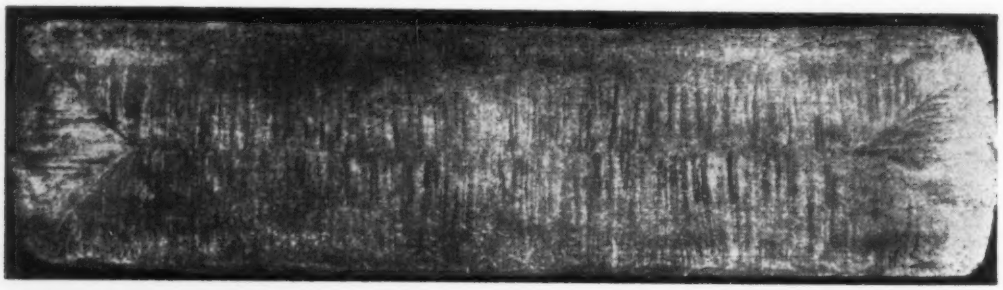


Fig. 14—Section of slab 150 mm × 600 mm (6 in. × 24 in.) of 18–8 Ti-stabilized stainless steel

filled with the mother liquor enriched with segregates. These so-called 'false' cracks are revealed in sulphur prints taken from samples of the cast metal.

Medium-carbon steels exhibit the greatest tendency to form cracks. Low-alloy chromium–nickel steels, carbon rimming steels, and transformer steels are less prone to this type of defect.

Investigations have shown that the number and extent of internal cracks are reduced when water consumption is less than 1·5 l./kg (0·14 gal/lb) of steel. There was also an increase in central porosity, but this did not adversely affect the quality of the rolled product so far as the types of steel examined are concerned. The degree to which any given factor in the continuous-casting process affects the quality of the cast product depends on the shape and size of the latter.

Round sections are the most difficult to produce with regard to the formation of both external longitudinal cracks and internal cracks. Solidification in a round billet is completed in a restricted region along the axis and all shrinkage and segregation defects are concentrated in the centre of the billet.

A square section is less rigid than a round one because the faces of a square can deflect to some extent. There is consequently less danger of formation of internal cracks. As regards shrinkage and segregation defects, a square billet possesses no advantages over the round.

A rectangular section is least prone to the formation of internal cracks because its wide faces impede shrinkage of the internal layers to a relatively small extent. When freezing is complete, the crystallites growing from the wide faces do not interlock at one point, as in a round or square section, but all along the major axis of the cross-section. Shrinkage and segregation defects are therefore concentrated along this axis. The higher the ratio of slab width to slab thickness, the greater the danger of external longitudinal cracks along the wide faces of the slab. These cracks are associated with non-uniform cooling and shrinkage of the slab shell as it freezes in the mould.

The main factors in the continuous casting of several qualities of steel in the form of rounds, squares, and rectangles are presented in Table I.

QUALITY OF THE CONTINUOUSLY CAST PRODUCT AND OF THE FINISHED ROLLED PRODUCT

If careful attention is paid to the conditions of melting and pouring, the quality of the cast products in medium-carbon steel, tool steel, low-alloy steel, and transformer steel is comparable with that of a conventional ingot of similar cross-sectional area. The internal structure of the continuously cast product exhibits considerably more central porosity and some small cracks sometimes filled with segregates (so-called 'false' cracks) appear. The surface quality of the continuously cast product in the steel qualities mentioned above is markedly superior to that of a conventional ingot. The continuously cast product can be fed to the rolling mills with practically no previous surface dressing. The distribution of segregates is more uniform, both transversely and

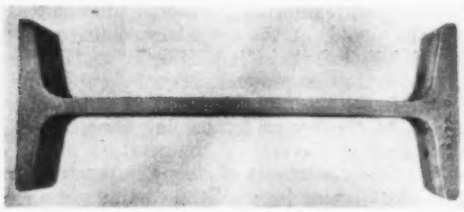


Fig. 15—Section of a beam rolled from a 200 mm × 200 mm (8 in. × 8 in.) bloom of medium-carbon steel

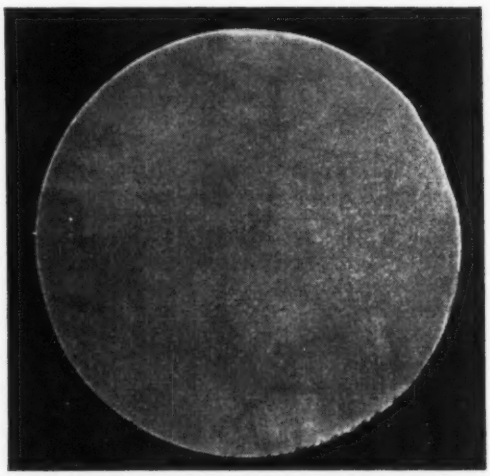


Fig. 16—Section of 90 mm (about 3½ in.) dia. round rolled from a billet 150 mm × 200 mm (6 in. × 8 in.) of 0·7%C tool steel

TABLE I

Operational factors in the continuous casting of steel

Type of steel	Shape and size of casting, mm	No. of strands	Ladle capacity, tons	Metal temp., °C	Casting speed, mm/min		Intensity of secondary cooling water consumption, l./kg of steel	Lubrication of mould	Notes
					Optimum	Maximum			
Medium-carbon steel: 0·14–0·30%C	ϕ 280	1	1·5	1 540–1 560	600	940	< 1·0	...	a
	200 × 200	2	10	1 600–1 620	700–1 100	1 200	0·25	Liquid paraffin	b
	150 × 475	1	10	1 570–1 595	700–1 000	1 300	0·9–1·3	,, ,,	b
	350 × 350	1	5	1 520–1 550	500–600	730	3·0–5·0	,, ,,	d
	175 × 420	2	50	1 540–1 560	800	1 000	1·5–2·0	,, ,,	c
Carbon steel: 0·7–0·8%C	200 × 200	2	5	1 580–1 600	600–800	1 000	0·25	,, ,,	b
Low-alloy Ni–Cr steel	150 × 475	1	5	1 590–1 610	800	900	0·8–1·0	,, ,,	b
Transformer steel: 3·0–4·6%Si	150 × 475	1	5–10	1 560–1 580	600–800	800	1·0	,, ,,	b
	200 × 200	2	5	1 580–1 610	900	1 000	0·25–0·85	,, ,,	b
18–8 Ti-stabilized stainless steel	150 × 600	1	18	1 590	1 100	1 200	unlimited	Silvered graphite	d
	175 × 300	1	18	1 590	1 200	1 200	Wooden boards are placed on the metal surface in the mould		

(a) Semi-continuous casting through pouring channel
(b) Continuous casting through tundish of 1·5 tons capacity
(c) Continuous casting in two strands through tundish of 3·5 tons capacity
(d) Semi-continuous casting through tundish of 0·5 tons capacity

longitudinally, compared with a conventionally poured ingot. This favourable factor is specially important in the casting of transformer and low-alloy steels. It is possible that, in this connection, the ductile properties of the finished product rolled from the continuously cast product—particularly in the case of sheets—are higher than those of sheets produced from conventional slab ingots. Because of the high surface finish of the sheets rolled from continuously cast slabs, the finished product is generally obtained without any extra dressing.

The production of 18–8 titanium-stabilized stainless-steel sheets from continuously cast slabs, however, presents a very different picture. The poor surface finish of the slabs requires the planing of all faces. In spite of this the rolling of slabs into 5–14 mm ($\frac{13}{64}$–$\frac{35}{64}$ in.) thick plates without intermediate dressing does not produce good-quality plate. The surface is very shelly and is difficult to dress. Good results were obtained with the cold rolling of sheets as, in this case, there are three stages of reduction and the material is thoroughly cleaned up and partially emery-dressed before rolling.

The internal structure of the various qualities of rolled sections produced from the continuously cast product is basically no different from that of conventionally rolled products. Any existing central porosity in carbon and low-alloy steels heals up completely after as little as five reductions in rolling. The mechanical properties of specimens taken from the central and peripheral zones are practically equal (Table II).

In some cases, macro-examination revealed highly etched bands on the specimens from both sheets and sections. These bands were 'false' cracks that had been rolled out and did not cause any deterioration in the mechanical properties of the steel.

Figures 10–16 are photographs of the macro-structure of cast and rolled medium-carbon steel, transformer steel, stainless steel, and tool steel. A wide range of carbon and low-alloy steels, already amounting to tens of thousands of tons, has been rolled into different sections from continuously cast billets and slabs and has satisfied all the requirements of Soviet State Standards specified by the consumers. This is evidence of the fact that the question of quality, which has until recently been the subject of a good deal of controversy, has now been answered in favour of continuous casting.

HEAT EXCHANGE AND SOLIDIFICATION OF STEEL UNDER CONTINUOUS CASTING CONDITIONS

An examination of the factors governing heat exchange and a study of the solidification of steel during the formation of the continuously cast product were a prominent feature of the research associated with the development of continuous casting.

The chief methods of determining heat exchange in the mould were by measuring the temperature to which the water is heated when passing through the mould and also the temperature of the copper walls at different points longitudinally and transversely in the mould. Data on the temperature of the copper faces enable us to calculate thermal currents, heat-transfer coefficients, surface temperatures, thickness of the freezing shell of the casting, and variation in shell thickness at various points over the length and width of the copper walls of square and rectangular moulds.

It was found that in the upper part of the mould, where the surface of the casting is in direct contact with the copper faces, the average value of the thermal current and of the heat-transfer coefficient does not in practice depend either on casting speed or on the dimensions of the faces of the cast product. The average value of the thermal current both for the wide and narrow faces of a slab, was found to be 1 500 000 kcal/m²/h, while peak values for the thermal current in individual periods reached 2 000 000 kcal/m²/h. The mean heat-transfer coefficient in the upper zone of the mould was 1 400 kcal/m²/h/° C.

Over the remaining length of the mould, where the surface of the casting is separated from the copper faces of the mould walls by a gas gap, the values of the thermal current and of the heat-transfer coefficient

TABLE II

Mechanical properties of metal rolled from continuously cast rounds, squares, and slabs after normalizing

Grade of steel	Section, mm	Dia., mm	No. of reductions	Tensile stress, kg/mm²		Elongation, %		Reduction in area, %		Impact strength, kg-m/cm²	
				Edge	Centre	Edge	Centre	Edge	Centre	Edge	Centre
Carbon steel, 0·12–0·22%C	200 × 200	90	6	59·0	57·8	31·4	28·4	64·0	64·1	12·5	12·5
	,,	,,	,,	64·7	64·0	28·0	27·0	56·7	56·4	9·2	8·4
Tool steel, 0·7%C	200 × 200	90	6	60·7	60·9	29·0	27·5	47·3	45·0	1·0	1·8
	150 × 200	,,	5	60·4	59·0	29·7	26·3	48·5	46·6	4·1	3·5
	,,	,,	,,	54·3	54·1	29·7	24·2	48·5	44·0	1·15	1·1
	,,	,,	,,	52·9	52·4	31·3	30·0	51·9	51·3	0·86	0·76
	ϕ200	70	8	54·5	54·3	30·9	27·6	50·8	46·0	2·0	1·0
	ϕ280	,,	16	54·1	59·2	28·3	26·0	46·6	42·6	0·63	0·63
Tool steel, 0·8%C–1·0%Mn	ϕ280	70	16	64·5	63·7	29·0	26·7	50·7	46·2	2·7	1·87

are related to casting speed and the dimensions of the slab face. In view of the relatively small extent of the ' contact ' zone, the values of thermal current and heat-transfer coefficient are given as averages for the entire working surface of the mould and also vary with casting speed and face dimensions (Fig. 17). At the same time, the variation in the speed of the water through the channels, within the limits of 4·3–7·4 m (14–24 ft) per second, had only a very limited effect on the total heat extraction from the mould (Fig. 18).

The use of a reciprocating mould somewhat increased heat extraction in the upper zone (by 5–7%) but, for the reason given above, did not affect total heat extraction.

When the data were processed, it was found that there was a relationship between average thermal current in the mould, casting speed, and dimensions of the faces of the slab:

$$q_H = \epsilon C_0 \left(\frac{T_{1H}}{100}\right)^4 + \frac{\lambda \cdot K}{\beta} \cdot \frac{2(t_{1H} - t_2)}{H(t_K - t_{1B})},$$

where

q_H is the thermal current perpendicular to face H

H and B are the dimensions of the adjacent faces of the slab

β is the coefficient of thermal expansion of the slab shell

t_K is the crystallization temperature of the steel

T_1 and t_1 are the temperature of the slab surface in ° K and ° C

t_2 is the temperature of the copper face of the mould wall

λ is the heat conductivity of the gap

K is an empirical coefficient used to calculate the possible deflection of the faces and depending on the ratio of the face dimensions H/B

ϵ is 0·62, $C_0 = 4 \cdot 96$ kcal/m²/h/° K.

t_1 is determined according to an empirical relationship

$$t_{1H} = (1\,200 + 100\,V)\,B^{\frac{0 \cdot 075}{V}}$$

where V is the casting speed in m/min.

The experimental data obtained show that the thickness of the copper faces of the mould walls has only a very slight influence on the amount of heat extraction in the mould. If the thickness of the copper facing is increased from 10 to 50 mm ($\frac{25}{64}$ to 2 in.), heat extraction is lowered by only 10%. At the same time, as calculations show, if the heat conductivity of the working face of the mould is reduced by substituting steel for copper, heat extraction is lowered by 25–30%.

The temperature of the copper faces of the mould walls depends mainly on the speed of the water through the channels in the mould. An increase in water speed above 10 m/s (32·5 ft/s) has practically no effect on wall temperature.

To reduce the harmful effect of the gas gap between the mould walls and the slab—which occurs, as the trials have shown, at a distance of as little as 150–250 mm (6–10 in.) from the liquid-metal level—moulds tapering inwards toward the bottom were used. An examination of the intensity of heat extraction in such a mould with a cross-sectional area of 150 mm × 500 mm (6 in. × 20 in.) showed that when the cross-sectional area of the mould was tapered from + 3·21% at the top to −1·06% at the bottom, heat extraction in the mould was increased from 208 to 267 kcal/s, or by 28·5%, with a withdrawal speed of 500 mm (20 in.)

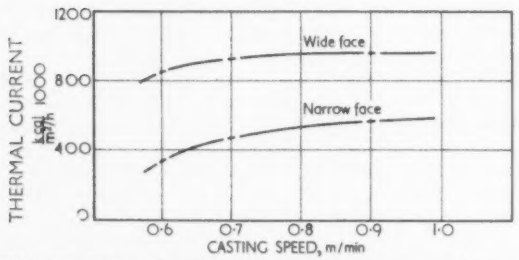


Fig. 17—Effect of casting speed and face dimensions on the thermal current at the surface of the mould for a 150 mm × 475 mm (6 in. × 19 in.) slab

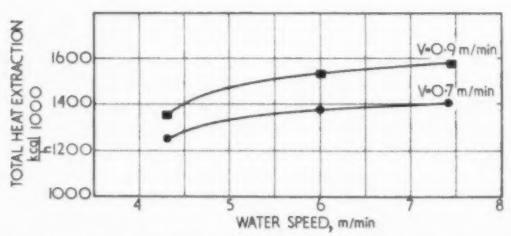


Fig. 18—Effect of cooling water consumption on total heat extraction for a 150 mm × 475 mm (6 in. × 19 in.) slab

per minute. Under these conditions, the shell thickness of the slab emerging from the mould is increased from 29 to 37 mm ($1\frac{9}{64}$ to $1\frac{29}{64}$ in.). The use of moulds with walls tapering toward the bottom made it possible to increase withdrawal speed, eliminate longitudinal external cracks, and improve the shape of the cast product.

Heat-exchange conditions in the secondary cooling zone were investigated by measuring the consumption and temperature of the cooling water, which made it possible to calculate the total quantity of heat extracted in this zone in unit time. A comparison of the data obtained with the results of mathematical calculations for some cases of cooling revealed a relationship between the volume of water consumed per square metre of surface area of the slab and the heat-transfer coefficients.

It was established that high rates of water consumption of the order of 30–80 $m^3/h/m^2$ of surface area of the slab ensure high coefficients of heat transfer of 1 000–7 000 $kcal/m^2/h/°C$.

Excessively severe cooling of the surface gave rise to internal cracks distributed over the cross-sectional area of the slab in a whole series of steels. Internal cracks can be avoided by lowering the heat-transfer coefficient in the secondary cooling zone to 150–550 $kcal/m^2/h/°C$, and this takes place with water consumption rates of less than 10 $m^3/h/m^2$ of surface area.

The peculiar features associated with the solidification of steel under continuous-casting conditions were studied by various methods: by the decantation method, by radiographic methods, by means of continuous liquid-steel measurements inside the slab, and by constructing water models. As a result of these investigations, empirical coefficients of freezing were determined for continuously cast products of various shapes and sizes and for a large range of steels, and the inter-relationships between these coefficients and the main factors of the continuous casting process were established.

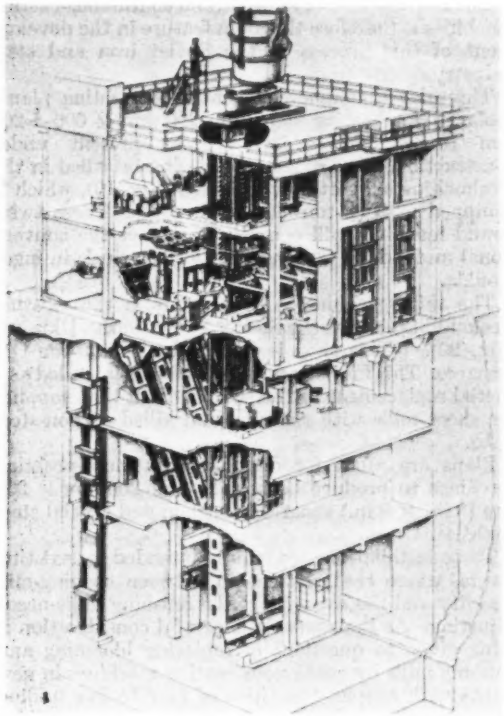


Fig. 19—Commercial continuous-casting machine at Novo Lipetsk

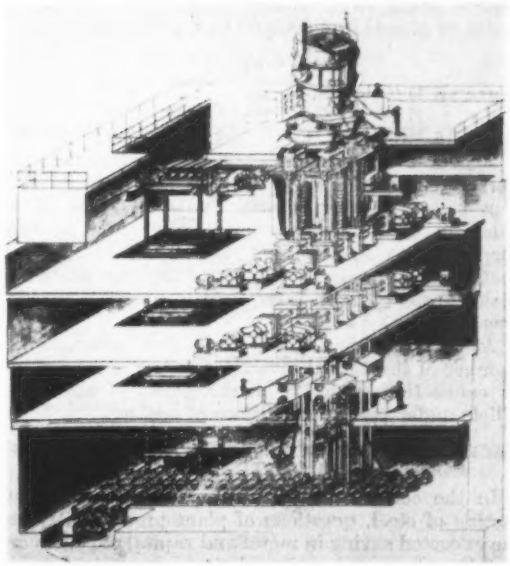


Fig. 20—Commercial continuous-casting machine at the Stalino works, Ukraine

It was found that the growth of the solid shell of a conventional ingot at the beginning of its formation is governed by a square root law:

$$\xi = K\sqrt{\tau}$$

where ξ is the thickness of the solid shell
τ is the time
K is the coefficient of freezing.

Depending upon shape and size of the section cast, the mould design, and the conditions of heat transfer in the gas gap, the coefficient of freezing varies from 2·2 to 2·9 $cm/min^{\frac{1}{2}}$. The properties of the steel cast only slightly affect the coefficient of freezing in the mould, since the thermophysical constants of the various types of steel are similar at temperatures above 1 000° C.

The freezing shell of the slab emerging from the mould is so thick (up to 30–40 mm, i.e. $1\frac{3}{16}$–$1\frac{37}{64}$ in.) that an increase in water consumption in the secondary cooling zone from 2–10 to 20–30 $m^3/h/m^2$ reduces the total freezing time throughout the section by only 10–15%. These data are evidence of the very limited possibility of accelerating freezing by applying large volumes of water in the secondary cooling zone.

The time required for the complete freezing of the section, and consequently the depth of the liquid phase, depend mainly on the shape and size of the

section being cast. Other things being equal, the depth of pipe is proportional to the casting speed:

$$L = \tau_K \cdot V$$

where L is the depth of pipe
V is the linear speed of casting
τ_K is the time required for complete solidification.

The time required for complete solidification also varies with the thermophysical properties of the steel. For instance, when casting slabs 150 mm (6 in.) thick in medium-carbon steel, the time required for complete solidification was 6–6·7 min. When casting the same-sized slabs in 18–8 titanium-stabilized stainless steel, the time required to complete freezing was as long as 8 min.

At the same time as the trials were undertaken, a number of theoretical investigations were carried out in connection with the solidification of slabs and billets under various conditions of cooling.

TECHNICAL AND ECONOMIC FACTORS IN THE CONTINUOUS CASTING OF STEEL

In the commercial application of the continuous casting of steel, questions of plant productivity and the expected saving in metal and capital expenses are decisive. From this point of view, economic data on the operation of the commercial plant at the Krasnoye Sormovo works are of great interest.

The investigations carried out showed that the use of the continuous method of casting eliminates metal losses such as occur in runners, short pours, and crop ends caused by variations in ingot weight arising from ingot mould wear. At the same time, new types of wastage occur in the continuous-casting process: burning losses that arise during the cutting of the slabs, top and bottom discards, and cropping necessitated by dimensional inaccuracy. The main items of metal loss are distributed proportionally as follows:

(i) Scrap in the tundish and burning losses during the cutting of the slabs on the continuous-casting machine 2·0%
(ii) Top and bottom discards and burning losses incurred during cutting off the separate lengths 1·3%
(iii) Rejection of slabs because of external cracks 3·2%
(iv) Rejection of slabs because of dimensional inaccuracy 1·3%

Average yield of sound castings from liquid steel was 92·2%, reaching 96·6% in some casts.

The continuously cast billet or slab does not contain any pipe and the product is not tapered. Its main advantages are therefore manifested during rolling. Under the conditions prevailing at the Krasnoye Sormovo works, it was possible to effect a saving in metal of 95 kg (210 lb) per ton of sheet rolled, i.e. an economy of 6·8% as compared with the production of sheets from conventional ingots. If the specific weight of the continuously cast slabs be taken into account when drawing up the metal balance-sheet for the sheet mill, productivity of this mill—and consequently labour productivity—was raised by 4·6%. Overall saving in metal from the melting charge to the rolled sheet, was 118 kg (260 lb) per ton of finished sheet or 7%.

The continuous-casting plant being built at the Stalino (Ukraine) works will, according to the Giprostal' plan, make it possible to increase the yield of saleable product by 11% compared with the actual yield from conventional ingots.

OUTLOOK FOR THE CONTINUOUS-CASTING PROCESS IN THE STEEL INDUSTRY AND THE RELATED RESEARCH AND DEVELOPMENT PROBLEMS

Extensive experience has now been obtained in the Soviet Union, enabling the use of ladles of up to 50 tons capacity for the continuous casting of steel.

The introduction of the process on a large scale in the iron and steel industry, however, demands the solution of questions regarding the pouring of slabs and squares from ladles of up to 270 tons capacity. This aim can be achieved in two ways.

The first method is to increase casting speed using a single mould. It has, however, already been shown that an increase in casting speed above a certain limit adversely affects the quality of the continuously cast product. In addition, the depth of the liquid phase in the casting is extended, and this is a factor which determines the overall height of the installation. An increase in overall height of the machine entails higher capital costs.

A second way offers far greater prospects. This involves multi-strand casting, i.e. the pouring of steel into several moulds simultaneously. This method of casting ensures high productivity with casting speeds best suited to produce a high-grade product. It has been established that much less capital is required for the building of multi-strand machines than for constructing several single-strand machines separately.

The introduction of multi-strand continuous-casting machines is therefore the main feature in the development of this process in the Soviet iron and steel industry.

Three large commercial continuous-casting plants designed for casting slabs 150–200 mm × 600–1 200 mm (6–8 in. × 25–48 in.) are at present under construction. Two of these are being installed in the steelmaking shop at Novo-Lipetsk (Fig. 19), which is equipped with 80-ton electric furnaces. These twin-strand machines will completely replace the conventional methods of pouring transformer steels in ingot moulds.

The third machine is being built in the existing steelmaking shop at the Stalino works in the Ukraine, (Fig. 20). This shop is equipped with 140-ton OH furnaces. This four-strand installation is intended as a partial replacement of the slabbing mill that supplies the sheet mills with rimming and killed carbon-steel slabs.

Plans are afoot for designing continuous-casting machines to produce both slabs and 200 mm × 200 mm (8 in. × 8 in.) squares in carbon and special steel qualities.

These installations are mainly intended for existing plants, where the relationship between cogging-mill capacity and the capacity of the finishing mills needs adjusting. At the same time, careful consideration is being given to questions of replacing blooming and slabbing mills by continuous-casting machines in new plants with output capacities of four to five million tons annually.

The construction of multi-strand machines for casting 300 mm × 300 mm (12 in. × 12 in.) or

350 mm × 350 mm (14 in. × 14 in.) squares from ladles of up to 270 tons capacity presents a serious problem. In this connection, much design work on multi-strand machines will have to be done.

The success to be achieved in the wide application of the continuous-casting process in the iron and steel industry and in its further development will largely depend on the solution of very many difficult theoretical and practical problems. One of the main problems will involve the selection of the range of cast products, not only as regards shape and size but also in respect of qualities.

First, the optimum conditions must be determined for the production of carbon, alloy, and low-alloy steel slabs with thickness to width ratios higher than 1 to 5. The continuous casting of rimming steel in various shapes and sizes and of high-alloy steels in squares and rounds presents urgent problems that must be solved.

If the technological problems are to be solved successfully, the properties of liquid steel and the mechanical properties of freezing metal at temperatures approaching freezing point must be studied. Questions of crystallization and structure formation in the continuously cast product require detailed investigation. In addition, effective methods must be devised to protect both plain carbon and special steels against oxidation during the casting process.

A study of the thermodynamics of the process will, of necessity, be of the utmost importance in the research and development work on the continuous casting of steel. Thermodynamics are of major importance as regards the mechanism of structure formation in the cast product, the determination of rational cooling conditions, mould design, and the construction of the secondary cooling equipment.

In connection with the present plans for operating large commercial continuous-casting machines, where the casting of a single heat will last 1–1½ h, the life of the refractory linings is vital. Quite apart from improving and perfecting the refractory materials at present in use, a great deal of research will have to be done to discover new types of super-refractories.

The problem of ensuring that the optimum operational conditions and parameters of the process will be kept constant so as to maintain uniform quality of the product and high productivity of labour is closely bound up with automation problems.

It is essential that there be automatic control of the factors governing the continuous-casting process. Provision must be made for automatic control of all technological operations, including cutting, removing, and stocking of the slabs or billets, and the entire control of the process will have to be concentrated at one point. A solution of this problem will enable the number of operatives to be markedly reduced, and will lower the accident rate and improve safety conditions, while greatly improving working conditions in steelmaking shops.

Continuous casting at Barrow

By Iain M. D. Halliday, B.Sc., A.R.T.C.

INTRODUCTION

THE CONTINUOUS CASTING PROCESS for steel developed at Barrow during the last six years is characterized by high casting speeds. Small-section billets, mainly 2 in. square, are cast at tonnage rates of about 7 tons/h, and ladles with 7–7½ tons of liquid metal are regularly drained under routine works conditions. The process was initially developed on a single-mould machine supplied for the most part with 4-ton lots of liquid metal. Later, the ladle charge was increased to about 7½ tons and the machine was converted to run as a twin-strand unit.

Special preheating arrangements have been developed so that steel at the furnace requires to be tapped only at normal, or lower than normal, temperatures. The casting period, normally just over 1 h on the single-strand machine, is only about ½ h when twin stranding, but under similar conditions casting has been continued through one mould for periods up to 2 h without loss of yield.

There are special arrangements for nozzle-pouring the liquid metal into the small-aperture moulds and for moving the moulds which are reciprocated vertically. Automatic controls have been developed on the twin-strand machine so as to maintain the required metal level within the mould during casting. The controls are so arranged that each strand starts its own drive when metal is supplied to it and each continues to operate at appropriate speeds until all metal has been drained from the pouring receptacles, whereupon the drive is stopped.

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SYNOPSIS

The continuous casting process developed at Barrow for the production of small-section steel billets and slabs at high speeds is described. Following a historical introduction, details of plant and procedure are given for single- or twin-strand operation with manual or self-start automatic control. Distinctive features are detailed under the headings: ladle, tundish, and non-swirl nozzle designs; preheat practice and theory; metal temperature control; mould design and operation; mould reciprocation on the Barrow principle with negative strip; mould life; suspended hollow-cone spray units; horizontal product discharge by bending; high average yields; product structure and quality. Finally, aspects of process economy and applicability are considered. 1657

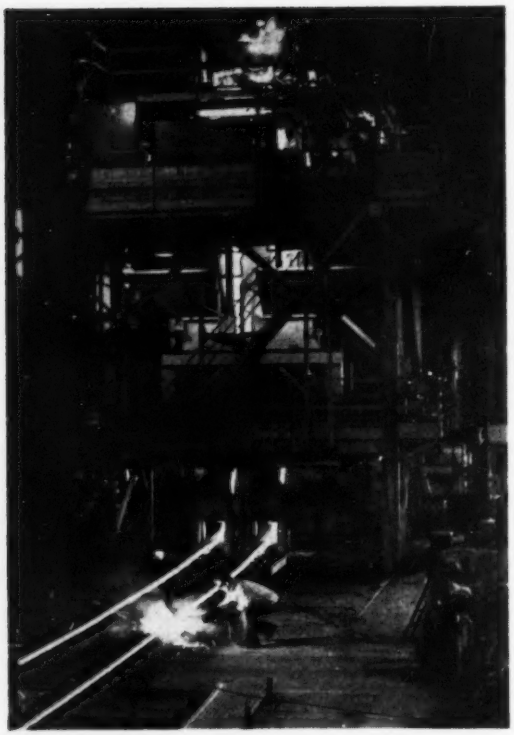

Fig. 1—General view of twin-strand continuous-casting machine

The cast sections, after descending through water sprays and a single driven pair of withdrawal rolls to ground level, are bent to discharge horizontally and any required length of product may be cut and collected on a hot bank. The metallic yield of good-quality cast product from liquid metal has been found in semi-production runs to average over 98½%. A view of the plant in operation is shown in Fig. 1.

HISTORICAL

The development of this process was undertaken primarily to meet the local requirements of the works at Barrow.

Barrow Steel Works Ltd.

In 1943 the Ministry of Supply had purchased from the Barrow Haematite Steel Company Ltd. the steelworks and re-rolling mills at Barrow and appointed The United Steel Companies Ltd. of Sheffield as their Managing Agents. The steelworks consisted of two open-hearth melting shops and a cogging and billet mill, whilst the re-rolling mills comprised three small bar mills and two hoop mills.

Early in 1953, the ownership of the Ministry of Supply works was transferred to the Iron and Steel Corporation of Great Britain and, subsequently, to the Iron and Steel Holding and Realisation Agency. On transfer, the name of the local works was changed to Barrow Steel Works Ltd. and The United Steel Companies Ltd. became the Managing Director.

Barrow requirements

In assessing the long-term development programme for the Barrow works, The United Steel Companies had recognized the advantages to be gained if a casting process could be developed to produce, direct from liquid metal, the small-section billets and slabs normally supplied to the re-rolling mills. In 1951 they suggested to the Ministry of Supply (and the Ministry agreed) that a continuous-casting pilot plant should be installed at Barrow to develop the casting of these small sections, namely, 2-in. square up to 4-in. square billets and also 6-in. × 2-in. slabs. Qualities covered the carbon steel range up to 0·80%C and included certain low-alloy specifications, for example, silico–manganese spring steel.

Available continuous casting experience

At this early stage continuous casting had developed to production methods in the non-ferrous field, notably for copper, brass, and aluminium. Although Bessemer's direct-casting machine for steel (1856) had marked the beginning of the subject, developments for steel were still, however, at the pilot plant stage or just emerging therefrom, and real experience, as far as was known from published literature, centred round the excellent pioneering work of the following concerns:

Country	*Year work started*	*Company*	*Plant*	*Plant capacity (in 1951)*
Germany	1943	Siegfried Junghans	Schorndorf	30 cwt
	1950	Mannesmann-Huttenwerke A.G.	Duisburg-Huckingen	5 tons
Austria	1947	Gebr. Böhler A.G.	Kapfenberg	6 cwt
U.S.A.	1946	The Babcock and Wilcox Company	Beaver Falls, Pa.	5 tons
	1949	Allegheny-Ludlum Steel Corp.	Watervliet, N.Y.	3 tons

Nothing was known at the time of the production plant in operation at Ets. Jacob Holtzer, Unieux, France, or of any work in the U.S.S.R.

In the U.K. experimental data were freely available from the BISRA laboratory casting apparatus at Battersea. No information, however, could be obtained regarding the plant of Low Moor Alloy Steelworks Ltd., Bradford.

Available data showed that this background of experience was concerned mainly with the casting of large sizes at low casting speeds. Nowhere had 2-in. square billets, the main product required by the re-rolling mills at Barrow, been cast on a routine basis and the highest casting speeds then known were in the range of 24–36 in./min.

Terms of Reference for Barrow

Process development by works trials was therefore envisaged from the start. Many problems were involved, e.g. the development of techniques for liquid metal handling, for control of casting and of product quality, and even the simple question of pouring steel cleanly into a 2-in. aperture mould. By far the most important point was that for any method to be economically worthwhile it would be necessary to establish the casting of the small sections required by Barrow at relatively high casting speeds, 5–10 times faster than any speeds then known.

The Terms of Reference for the work at Barrow, as stated in 1951, set the target. These were briefly:

(i) To cast 2-in. square mild-steel billets at 5 tons/h on a routine basis, in one mould if possible and using a machine crew of only three men

(ii) To devise metal handling and holding techniques so that hot metal, as tapped from OH furnaces, could be continuously cast on a production basis

(iii) To obtain technical data and cost estimates on which to design a production plant for Barrow Steel Works.

A production rate of 5 tons/h for 2-in. square billets means a casting speed of 180 in./min. When the casting of 2-in. billets had been more or less established at average speeds of 240 in./min, a fourth term was added in March, 1954, namely:

(iv) To cast 2-in. square mild-steel billets of good quality at a casting speed of 1 000 in./min on a routine basis in one mould.

No reference will be made in this report to work done in connection with this more advanced level of operation, except to note that, in fact, casting was established at speeds averaging 450 in./min (maximum 570 in./min) on 2-in. billets.

Rossi agreements

During 1951 The United Steel Companies agreed contracts with Mr Irving Rossi of New York for the supply of a pilot casting machine and for the right as licencees to use the Rossi–Junghans process. At the time this process had been applied commercially in the non-ferrous field, but for steel it was still under development on the pilot machine at the Watervliet works of the Allegheny-Ludlum Steel Corporation.

Three contributory factors encouraged The United Steel Companies to make these agreements:

(i) Their desire to proceed from a sound basis of 'know-how'

(ii) The high standard of performance achieved by the Allegheny-Ludlum Steel Corporation on their pilot plant at Watervliet, N.Y., where 3¼-in. square billets were being cast at speeds up to 36 in./min, and later up to 42 in./min

(iii) Mr Rossi's courage in undertaking the initial design of a machine suitable to Barrow requirements. There is no doubt that Mr Rossi's enthusiasm gave considerable impetus to the early work and contributed much to later development.

Initial installation of pilot plant

The United Steel Companies co-operated with Mr Rossi in the design and construction of the initial machine. The principal aim was to provide facilities, whereby the casting of 2-in. billets could be developed through one mould at least to speeds of 180 in./min, whilst the metal supply to the machine was to be taken in ladles from furnaces sited at ground level and not, as in certain other cases, from a furnace on top of the machine support-tower.

To develop the process, Mr Rossi supplied a suitable machine with an upper speed limit of 320 in./min. Ladles and suitable structures for teeming metal on the top platform of the tower were provided by Barrow Steel Works who, together with The United Steel Companies, were responsible for the supply of suitable metal, the operation of the machine, and the day-to-day development of the process.

The tower and contained machinery were erected at the north end of the existing north-end casting pit, the building being extended and increased in height so as to accommodate a gantry crane of 15-tons capacity with a maximum crane-hook height of 46 ft. Alongside the casting tower, and serviced by the same crane, a 5-tons capacity basic arc furnace with a 2 400 kVA transformer was installed to supply liquid metal for the experiments. Site conditions were so arranged that metal from the 40-ton OH furnaces then in operation at Barrow could later be brought to the machine. The first trial was made on 2nd December, 1952.

The arc furnace allowed metal for trial casts to be supplied as and when required and at suitable temperature. A double slag process was adopted at the furnace and in the early trials it was often necessary to tap the metal at temperatures up to 150° C hotter than for orthodox ingot practice. It was only after ladle preheating and hot metal handling techniques were developed that runs with OH steel could be undertaken. With the arc furnace most of the slag was removed from the metal before tapping into the ladle, thus reducing ladle lining attack and minimizing change of metal analysis during teeming. Lip-pour ladles were adopted to transfer the metal to the machine and, to preserve heat, these ladles were fitted with lids.

The design of the machine initially installed need not be detailed since all the main features have radically changed with the development of the process. It is enough to say that the machine was based on the Rossi–Junghans principle of casting with a reciprocating mould, the mould itself being constructed in two pieces from heavy forged blocks of pure copper.

As built, the machine had certain facilities for twin stranding. The initial tundish installation comprised a pair of tilting tundishes set side by side and designed to nozzle-pour into two moulds mounted on a common support table and reciprocated by means of a single cam driven through gearing by a 5-h.p. motor. This motor also drove a single horizontally placed withdrawal roll common to both strands. A small undriven withdrawal roll was arranged, when spring-loaded, to press against the driven roll for each strand of the machine. Throughout the early years, however, The United Steel Companies concentrated on casting through one mould until the process was established on a reliable and repeatable basis at suitably high tonnage rates.

The initial discharge equipment consisted of a horizontally traversing torch and a pneumatically powered tilting frame carrying a movable 'basket' to eject the cut-off billet lengths horizontally. Control was by a somewhat complicated system of pneumatic–magnetic limit switches.

Casting machine operatives

The casting machine was manned initially by a crew of only three men; ladleman, mould operator, and a cut-off and discharge operator. In addition to the social problems of selection and training, preparatory and operational duties were gradually standardized so that in 1954, when a second crew of three men was engaged, their basic training required about 4 weeks, or 20 casts.

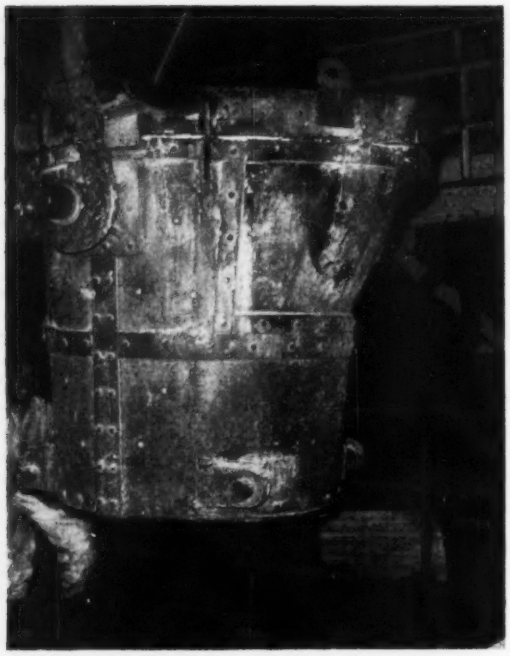

Fig. 2—Lip-pour ladle fitted with lid

Before the first trial the whole process had been surveyed in a 'job hazard' analysis. This exercise proved extremely valuable in obviating mistakes and the establishment of safety precautions before tackling new operations has likewise been useful.

Much importance was, and still is, attached to the need for the operators to work as a team, and to careful observer training. With the process as now developed, because of simplification and greater reliability, it may well be possible to train new men fairly quickly, e.g. in about 3 weeks. Only time brings experience and it is not yet known how long trainees under production-plant conditions will need to become fully experienced. On the other hand, many of the experiences of the earlier days need not be repeated and, in this connection, the author would record his debt to the three men who formed the initial crew: Mr Roy Millard (mould), Mr Isaac Benn (ladle), and Mr Bert Calderbank (cut-off), all of Barrow Steel Works. Almost as much indebtedness is due as well to the members of the second crew: Mr William Caldwell (mould), Mr David Haney (ladle), and Mr William Marklew (cut-off), also of Barrow Steel Works.

In May, 1954, Mr Eric Grayson joined the continuous casting team as assistant manager to help in the day-to-day preparation and running of trials and to him the author would also record considerable thanks for his keenness and help.

Continuous Casting Technical Committee

In September, 1951, The United Steel Companies established a steering committee, known as the continuous casting technical committee. Having supervisory functions, this committee has guided the progress of development throughout.

Until 1957 the committee consisted of the following staff members of The United Steel Companies and Barrow Steel Works:

Mr G. N. F. Wingate (*Chairman*), Capt. W. F. Baily, Dr J. H. Chesters, Mr J. H. Flux (*Secretary*), Mr I. M. D. Halliday, Mr J. Lyon, Mr T. G. Marple, Mr F. H. Saniter.

In 1957 and 1958, respectively, the committee invited two additional members of The United Steel Companies to join. They were Mr R. Wilcock and Mr A. Jackson. To this date the committee has sustained no loss of membership.

Progress of development

Altogether 869 casts have been made at Barrow. Of these, 787 were carried out on the single-strand machine and the remaining 82 on the twin-strand machine.

Chiefly 2-in. square billets have been cast, but 3-in. square and $3\frac{5}{8}$-in. square billets and 6-in. × 2-in. slabs have also been produced. In general, the procedure developed for the casting of 2-in. square billets has proved directly applicable to operations on these larger sections.

Most of the runs have been made with carbon steels in the range 0·05–0·85%C. Certain low-alloy steels have also been cast, e.g. silico–manganese and manganese–molybdenum spring steels, and high-sulphur free-cutting steel. Certain high-alloy steels have also

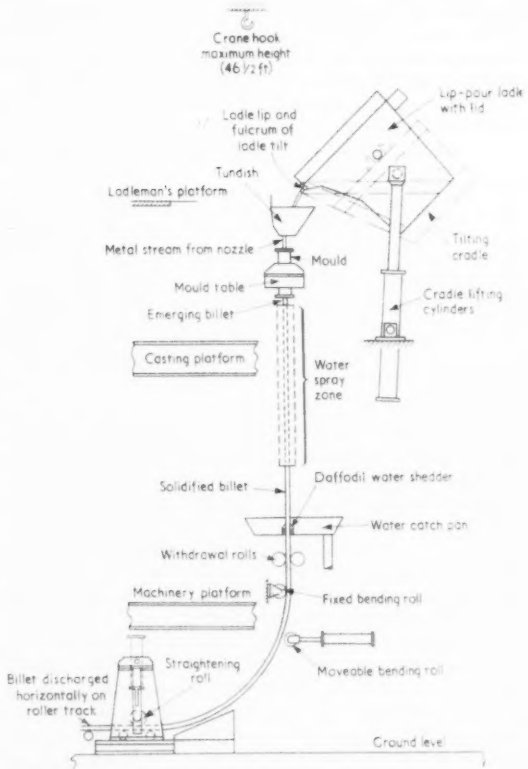

Fig. 3—Vertical disposition of main parts of single-strand machine developed at Barrow (side view)

been produced, mainly 18–8 Cr–Ni stainless qualities and some high-nitrogen valve steels. The techniques involved for all these qualities are essentially similar. Only killed steels have been cast to date although one attempt has been made to cast rimming steel through a 2-in. mould.

The progress of development at Barrow is briefly reviewed in the Appendix, which gives a historical summary against trial numbers and dates. The Appendix lists only the more decisive or noteworthy steps by which the process was evolved and throws some light on the scope of the work, including time devoted to semi-production runs and certain special issues.

Thus, early in 1953 it was found possible to establish the casting of 2-in. square billets, for short periods, at progressively higher casting speeds, e.g. 150, 175, and 200 in./min in trials nos. 43, 45, and 51. It was not, however, until almost a year later, (trial no. 210, on the 20th February, 1954) that a ladleful of metal could be emptied fairly frequently into the machine with some assurance, and it required about a further year's work to establish a reliable practice by which the ladle could be drained regularly. This was proved in the consecutive reliability trials, nos. 368–377, undertaken during the period 9th–19th March, 1955.

Whilst the work at Barrow has been concentrated essentially on development and gaining information, the establishment of a reliable process under works conditions was, of course, the main aim. The achievement of this condition is perhaps best demonstrated by the performance during the reliability trials on the twin-strand machine, trials nos. 803–839 (23rd June–18th July, 1958). In this 4-week period (5 days per week), 37 casts were run and a total of 256 tons of 2-in. billets (45 056 ft altogether) were produced by twin stranding under automatic control conditions at an overall average yield of 98·5%. All the product was re-rolled to finished sections and sold.

DESCRIPTION OF PLANT AND PROCESS

The casting process at Barrow was established initially with 4-ton metal charges taken from the arc furnace. Trials with OH metal were made before 1955 and, as seen in the Appendix, it was in April, 1957 that the arc furnace and ladle capacities were increased to 7½–8 tons. Only minor differences were associated with the increase in capacity.

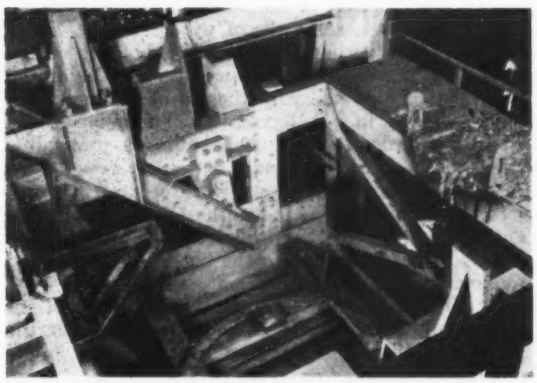

Fig. 4—Construction of tilting cradle for lip-pour ladle

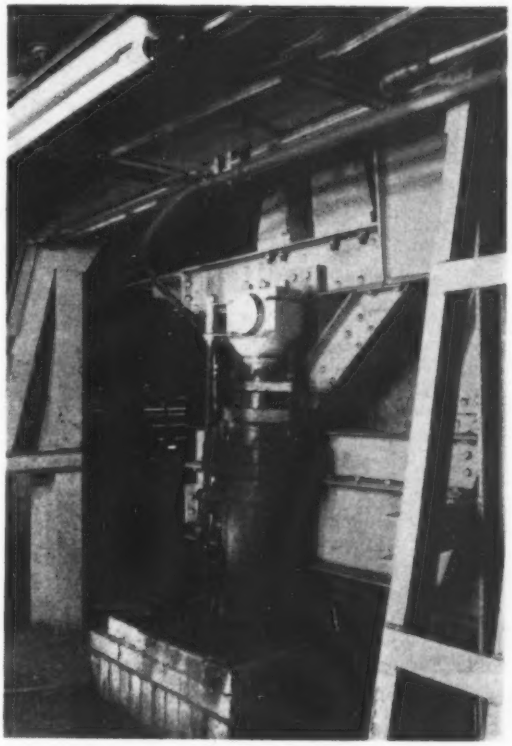

Fig. 5—Attachment of oil-powered lifting ram to outside of tilting-cradle frame

Metal transfer

Metal is transferred to the casting machine in a lip-pour-type ladle (Fig. 2) which, to minimize temperature loss when carrying steel, is fitted with a lid and preheated to about 1 520° C before receiving metal at the furnace. The lid has a centrally placed circular hole through which the ladle is oil-fired during preheating and casting by means of a specially designed combustion can or burner. Preheating has normally been done on top of the casting machine at Barrow, but in a production plant separate preheating stations would probably be installed.

On the side furthest from the pouring lip a rectangular filling hole is provided in the ladle lid. Three brick covers are placed over the filling hole during preheating and casting, but are carried in the open position when filling at the furnace and during transfer. Other features of the ladle are described later.

Trials with OH metal

Special tapping arrangements were made to fill the 4½-tons capacity casting-machine ladle for trials with OH metal. The casting-machine ladle was positioned beside the OH ladle and below a large-diameter stoppered pouring nozzle set centrally in the floor of the furnace tapping launder. On tapping, metal was first allowed to pass via the launder into the OH ladle until about one-quarter full. The launder

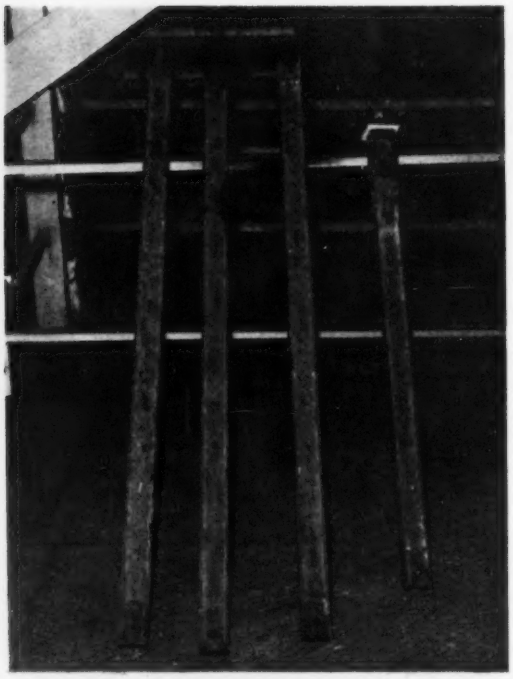

Fig. 6—Four lengths of typical dummy bar complete with head bolt and asbestos washer prepared before threading up through casting machine

stopper was then raised to permit some of the metal flowing from the furnace to discharge through the nozzle into the preheated casting-machine ladle.

Metal was therefore taken to the machine direct from the larger-capacity OH furnace without needing to decant from the OH ladle. OH metal could thus be cast under conditions approximating those for a casting plant built to a scale similar to that of the OH furnace.

Apart from a tendency for fairly heavy amounts of slag to collect with the metal in the ladle, the casting of OH metal presented no difference as compared with handling arc-furnace metal. The arc furnace, however, gives much greater control of tapping time, metal tapping temperature, and analysis.

Arc-furnace tapping procedure

Control of the casting process starts at the furnace. For a given metal analysis a predetermined tapping temperature is first obtained and checked by immersion thermocouple. Whilst slag is removed from the metal in the furnace, the ladle suspended from the crane hook is positioned with its filling hole close to the end of the furnace launder. The tapping operation is controlled by one man who orders the furnaceman progressively to tilt the furnace and, at the same time, calls for adjustments to be made in the position of the ladle. In this way the furnace is tilted through its tapping angle whilst the ladle is progressively moved so as to ensure that the whole contents of the furnace enter the ladle.

A standard time is allowed for the tapping operation; $2\frac{1}{2}$ min for tapping a 4-ton metal charge and $3\frac{1}{2}$ min for 7 tons. Tapping time is standardized so as to secure a standard drop in metal temperature for its transfer from furnace to ladle and thus maintain control of metal temperature. Sometimes, however, the tapping time is altered on purpose, but only as a corrective measure if, say, the bath temperature before tapping has been raised higher than necessary or, as in certain emergencies, has to be accepted somewhat lower than normal. In the former case the time of tapping is extended sufficiently to cool the metal to the required temperature, whilst in the latter, the furnace is tapped rapidly to save heat. Thus, on occasion, tapping times have varied from about 7 min to 1 min for the $4\frac{1}{2}$-ton ladle and to just under 2 min for the $7\frac{1}{2}$-ton ladle.

When using the $4\frac{1}{2}$-ton ladle the metal lost only about 30° C during tapping and transfer to the machine, and with the 8-ton ladle it normally loses only about 25° C. Conditions are arranged so that when the ladle is set down on top of the machine the metal has to cool a little further to a predetermined temperature before starting to cast.

CASTING MACHINE OPERATIONS

The descriptions which follow of the starting and operating procedures for the established process have been prepared in the form of two ciné films, "Continuous Casting of Steel at Barrow," completed in 1956, with an appendix "Horizontal Discharge by Bending" added in 1958, and "Twin-strand Continuous Casting at Barrow," completed in 1958.

Single-strand machine

Figure 3 shows diagrammatically the vertical disposition of the casting machine which is supported on a tower constructed with two main platforms. On the top platform the ladle is placed in a tilting cradle, which tilts about a fulcrum line coinciding with the discharge point of the ladle lip. The construction of the cradle is shown in Fig. 4, whilst Fig. 5 shows one of the two oil-powered rams which lift the cradle.

A pouring box, or tundish, receives the metal from the ladle lip and is positioned to discharge in a vertical stream through its refractory nozzle into the mould. The latter is supported on a mould table (not shown in Fig. 3), which is reciprocated vertically by a cam-and-link system during casting. A pool of metal is formed near the top of the mould when casting and the billet section, the walls of which solidify within the mould, is withdrawn from the bottom of the mould by means of withdrawal rolls. The initial movement is obtained with the aid of a dummy bar which, as seen in Fig. 6, consists of four lengths of fabricated girder section, each having a protruding spigot at its upper end and a matching socket at its lower end. When fitted together and secured by transverse taper pins the four lengths form a single bar. The top end of this bar is fitted with a solid head corresponding in section to the bottom of the mould and carrying a protruding bolt, also secured by a taper pin. Before starting, the dummy-bar portions are joined together and threaded up through the machine until the head bolt moves into the mould and the head of the dummy bar seals the bottom of the mould tube with the aid of an asbestos washer.

On emerging from the mould the billet still has a liquid centre. It descends through a zone of directly applied water sprays wherein the solidification process is completed. The billet then descends through a water catch-pan and a special water shedder known as a ' daffodil ' to the withdrawal rolls below. The latter grip the billet under an applied spring load and control its descent. These rolls are driven through infinitely variable gears by a 5-h.p. a.c. motor, which also drives, through a parallel gear train, the cam-and-link system to reciprocate the mould. Below the withdrawal rolls the billet descends to a pair of bending rolls, one fixed and one movable, which bend and discharge it horizontally along a roller path. The billet normally straightens under its own weight on to the roller track, where it is cut to required lengths and removed to a hot bank.

Casting procedure with manual control

The single-strand process may be described more fully by following the procedure used during a cast run by the basic method of manual control. Automatic control procedure, though perfectly feasible for single stranding, will be referred to later in connection with the twin-strand machine.

Whilst the ladle is receiving metal at the furnace final preparations are made at the machine. The tundish, set in position above the mould and fitted with a cover of three suitably clamped brick arches, has already been preheated to about 1 500° C by firing with a small combustion can, similar to that used for preheating the ladle. Like the ladle combustion can, the tundish burner is independently supported and able to swing clear for setting the tundish in position or removing it. In preparation, the mould operator checks that the tundish cavity is clear of any small pieces of refractory cement or brick and, if necessary, clears these using a suction gun. An oxy–propane torch is lit and placed on top of the mould to preheat the refractory nozzle carried in the bottom of the tundish. Using a mirror, the operator checks that the flame is firing correctly up the bore of the nozzle.

The ladle, full of liquid steel, is lifted by the crane to the top of the machine and, carried pouring-lip first over the side of the top platform, is then lowered into the tilting cradle. When set down the ladle is self-positioning and the crane hooks can be removed. Safety pins are fitted and the three brick covers are swung over the filling hole.

The steel temperature in the ladle is again measured to ensure control. Special thermocouple-type pyrometers are dipped into the metal through the burner aperture to record the temperature. The initial temperature of the metal on reaching the machine is usually a little higher than required for casting and, from experience, the approximate time is judged for the metal in the ladle to cool to the predetermined casting temperature. During cooling the ladle is allowed to stand and is not fired. At the estimated time, metal temperature is again measured and rechecked to confirm it has reached the predetermined level before pouring. This casting temperature depends upon metal quality, e.g. 0·20%C steel is taken at 1 560° C.

Fig. 7—Mould operator manually controlling casting of 2-in. square billet at 240 in./min

The tundish cover below the ladle lip is then removed and the ladle combustion can heater is swung over the ladle lid and pinned into position. It is lit simply by pressing two push-buttons to switch on the oil pump and air fan and thereafter this burner continues to fire the ladle throughout the cast which, with a 7½-ton ladle casting 2-in. square billets, usually lasts about 1 h. Ignition of the ladle burner is heard at ground level, where an operator lights the stand-by cut-off torch in preparation for casting.

All casting-machine operatives, who are dressed in protective asbestos jacket and trousers and leather boots, at this point put on gloves and steel helmets and, where necessary, protective glasses. In addition, mould operators are provided with a face shield of wire gauze attached to their helmets.

The mould operator then removes the nozzle preheat torch and clears the top of the mould. Mould cooling water is next turned on at the valve and the water circuit by-pass valve shut. The mould operator then positions a small mirror below the tundish so as to see the end of a piece of wire about 14 in. long, which he hangs inside the mould over the front edge. Having adjusted the rapeseed oil drip-feed pipes so as to overhang slightly the top edge of the mould, he then swings forward the hand controls which, mounted on a pendant, include the main drive starting-button and a change-speed lever.

The mould operator signals to the ladleman, who starts to tilt the ladle by opening a lever valve to supply oil under pressure to the cradle lifting cylinders. The ladleman is provided with a casting speed indicator and continues to tilt the ladle until the machine

Fig. 8—General view during casting showing tundish (top) with slag box (right), nozzle stream entering mould, and billet emerging below mould and entering top of water spray zone on single-strand machine

starts and the required casting speed is obtained. Thereafter, by regulating the oil supply, he controls ladle tilt to maintain the desired speed.

A flap launder is placed in front of the ladle lip and a heavy oxy–propane burner is used to give the lip a quick preheat. The first flush of metal from the ladle always has some slag mixed with it and is therefore run off by the launder into a slag box placed at the side of the tundish. In a few seconds the metal issuing from the ladle lip runs clear of slag, whereupon the launder is pulled away and the metal stream, by this time fairly heavy, pours directly into the tundish, where it starts to form a pool. When the launder is removed, the operators waiting at ground level to disconnect the dummy bar are warned by ' intercom '.

The steel soon establishes a steady stream from nozzle to mould and, in his mirror, the mould operator watches the metal rise as it fills the mould. When the metal touches the lower end of the wire he starts the machine; the mould begins to reciprocate and the rolls to withdraw the billet. The rapeseed oil-feed pump is energized simultaneously with the main drive and rapeseed oil begins to flow through its pipe system so as to drip at approximately the correct rate on to the top surface of the steel in the mould. The oil is dropped close to the meniscus of the metal against the mould wall, so that it spreads to cover the mould faces and thus provide lubrication. As soon as the machine drive is started propane gas is turned on to provide lambent flames around the tundish nozzle and the emerging metal stream, so as to blanket the steel against oxidation by atmospheric oxygen. In addition, the main control valve is opened to supply water to the billet sprays below the mould. In a mechanized plant both the propane gas and spray water valves would simultaneously open when the main machine-drive units are started.

The gearing of the main drive is preset so that on pressing the start button the machine starts to withdraw the billet from the mould at about two-thirds the expected casting speed. After beginning to fill the mould the nozzle discharge rapidly develops and the metal level in the mould begins to rise at speeds approaching the expected casting speed. When withdrawal is initiated at the preset speed, the metal level proceeds to rise more slowly and the operator has time to increase the withdrawal speed until he holds the metal level steady near the top of the reciprocating mould. Thereafter, the operator continues to adjust the speed of withdrawal so as to balance the discharge from the tundish at all times keeping the level in the mould as steady as possible at a given height. The photograph of the mould

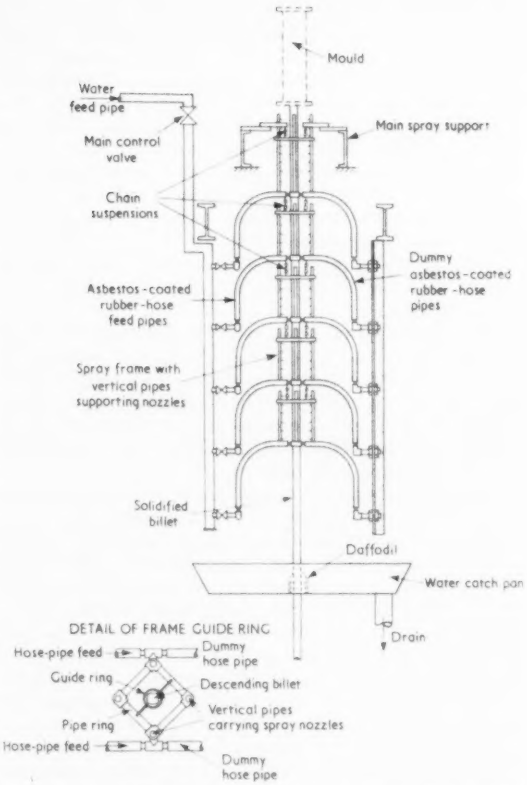

Fig. 9—General arrangement of suspended water sprays developed for continuous-casting machines

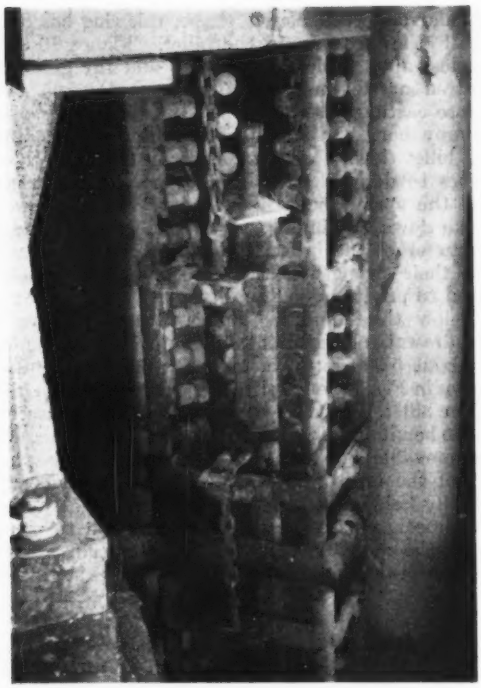

Fig. 10—Most recent construction of chain-suspended water spray units as used at Barrow seen before casting and showing dummy bar head before being raised to close bottom of mould tube

operator manually controlling the casting of 2-in. square billet at 240 in./min (Fig. 7) shows his hand controls and standard dress; also seen are the metal stream entering the mould and the metal level in the mould.

The mould is constructed from a pure copper tube with $\frac{1}{4}$ in. corner radii and $\frac{1}{4}$ in. wall thickness. The

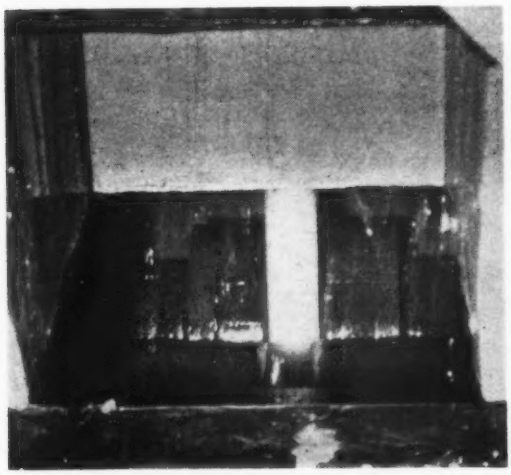

Fig. 11—Close-up view of 2-in. square billet descending through withdrawal rolls

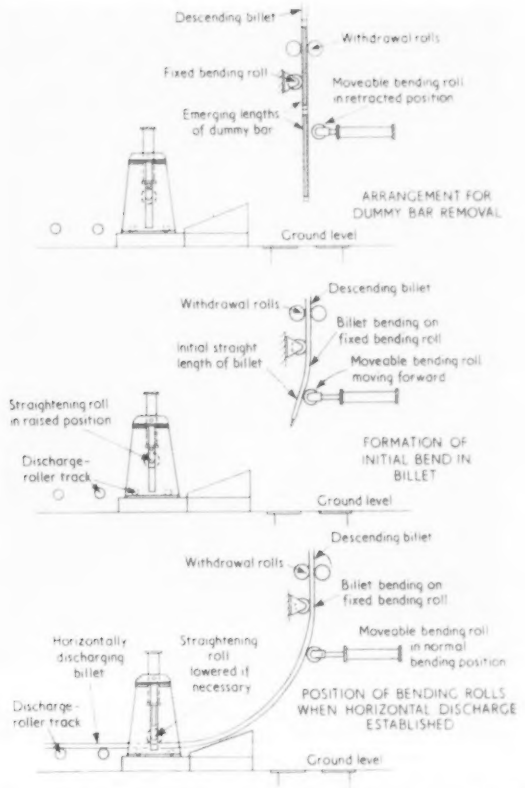

Fig. 12—Diagrammatic illustration of use of bending rolls for horizontal discharge of continuously cast billets

tube is just over 32 in. long and a copper flange is brazed to its upper end for support. The tube is surrounded by a steel casing which forms a $\frac{3}{16}$-in. annulus up which cooling water is passed at a velocity of 25 ft/s. The water is supplied through pipes to a feed chamber at the bottom of the casing and likewise conducted away at the top. About 140 gal/min are used at 45 lb/in^2 and in cooling the mould the water picks up about 10° C. To start a cast the bottom of the mould is closed by the head of the dummy bar, the $\frac{3}{4}$-in. bolt protruding upwards inside the mould tube. Some six or seven steel slivers are placed around the bolt so that the initial stream of metal solidifies quickly around its head.

The speed of reciprocation of the mould during casting varies with the descent speed of the billet. The latter, controlled by the speed of the withdrawal rolls, and the former, by the speed of the cam-and-link system, are both varied simultaneously by the mould operator, using the change-speed lever. Reciprocation of the mould is arranged so that it is moved down at a slightly faster speed than the billet for three-quarters of each cycle and is then raised quickly during each remaining quarter cycle, as will be detailed later. The downward movements of the mould hasten initial solidification of the billet skin by providing almost static conditions at the mould

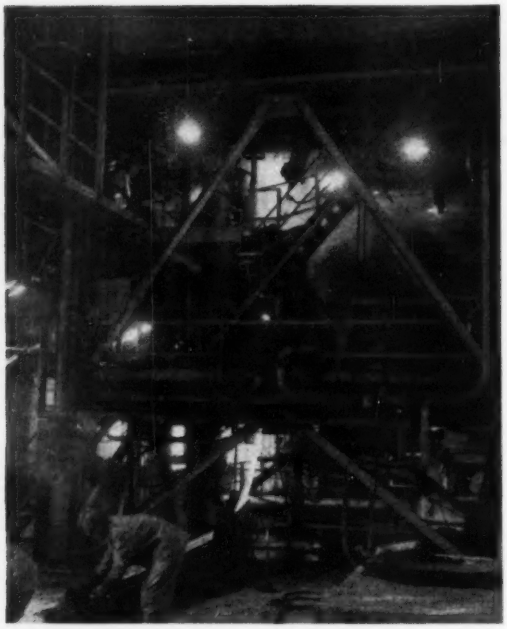

Fig. 13—General view of single-strand machine casting 3-in. square billets (August, 1956)

faces and the upward strokes give regular stripping action. Mould stroke length is usually chosen at 2 in. for the casting of 2-in. square billets.

On starting, the dummy bar pulls the newly cast billet downwards into the spray units. Figure 8 is a general view showing the tundish with the slag box at its side, the nozzle stream, the mould being reciprocated on its table, and the billet emerging below the mould into the upper spray unit.

The sprays complete the solidification of the liquid centre of the billet by impinging directly on to its surfaces. Spray nozzles on pipe frames are suspended from brackets below the mould by means of short chain lengths between each section, as shown in Fig. 9. The spray units are thus able to swing so as to follow small lateral movements of the descending billet and maintain even cooling. Each spray unit is supplied by individual flexible feed-pipes, which are connected through valves to the common water-supply pipe. Because the feed-pipes tend to straighten under water pressure when spraying is begun, each pipe frame is fed through two hose-pipe connections and dummy hose pipes of the same length, but opposing curvature, are fitted opposite each connection. The dummy pipes are permanently blocked off at their extremities where they are also rigidly held. Water pressure then affects both the feed-pipes and the dummy pipes on each frame and the forces tending to straighten the hoses balance. The spray units are thus not subjected to side forces and can move freely on their chain connections when spraying is in progress.

To ensure symmetrical application of the sprays on all four faces of the billet as it descends, each pipe frame is fitted with a guide ring at its lower end. Circular or rectangular in shape, this ring has only a small clearance around the billet. Figure 10 shows in close-up a typical pipe frame and the guide ring centred at its lower end. This photograph taken before casting, also shows the head assembly of the dummy bar. On starting, the dummy bar threads the billet down through the spray frames. It continues to descend with little or no side movement; had the sprays been fixed rigidly the billet would snake down continually. The sprays determine the character of the internal solidification of the billet, and their strength is therefore varied with casting speed to produce good quality.

Below the 'daffodil' and water catch-pan, the withdrawal rolls grip the billet under a spring load of about 5 000 lb. The rolls are 6 in. dia. and, as shown in Fig. 11, one roll is flanged to guide the billet.

The billet, guided by the dummy bar, then descends to the bending rolls. As seen in Fig. 12 (top diagram) the movable bending roll mounted on the piston rod of the horizontally supported power cylinder is initially held in its retracted position. The dummy bar descends past the fixed bending roll to emerge below the movable bending roll, where an operator disconnects each section in turn by knocking out the

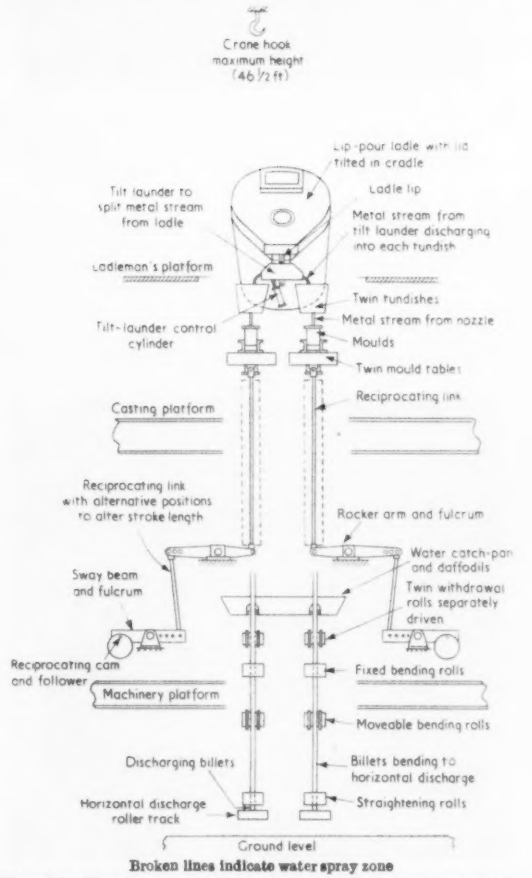

Fig. 14—Vertical arrangement of main parts of twin-strand continuous casting machine (front elevation)

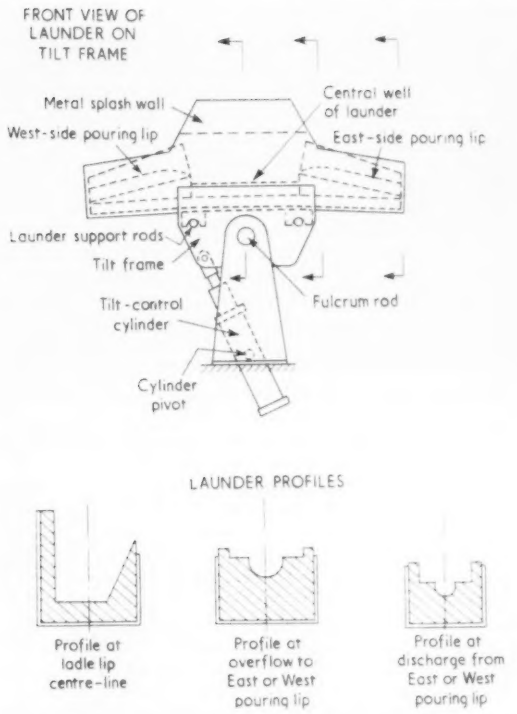
FRONT VIEW OF LAUNDER ON TILT FRAME
Metal splash wall
Central well of launder
West-side pouring lip
East-side pouring lip
Launder support rods
Tilt frame
Fulcrum rod
Tilt-control cylinder
Cylinder pivot
LAUNDER PROFILES
Profile at ladle lip centre-line
Profile at overflow to East or West pouring lip
Profile at discharge from East or West pouring lip

Fig. 15—General arrangement and profiles of launder on tilt frame developed at Barrow to split metal supply for twin-strand machine

taper pins at the spigot and socket joints. When the last section has been removed and the hot end of the billet emerges, the operator opens a pressurized-oil control-valve and moves the bending roll forward to bend the billet as it continues to descend.

Bending is effected against the fixed bending roll but, as shown in Fig. 12 (middle diagram), the initial length of billet remains relatively straight and to compensate for this in making the initial turn of the billet towards the discharge roller track the movable roll is brought forward further than would otherwise be necessary. This temporarily accentuates the bend so as to ensure that the end of the billet moves cleanly into the gap between the straightening rolls. To facilitate the operator's judgment a sloping floor plate is positioned in front of the straightening rolls. This plate can also act as a deflection surface, but is not normally required to do so.

To complete the initial turn the operator adjusts the movable bending roll, inching it forward when necessary to raise the end of the turning billet but, in general, retracting it progressively from its initial far-forward position. The movable bending roll is finally brought back to a position which produces just sufficient bending action to ensure that the billet moves steadily along the discharge roller track, as indicated in Fig. 12 (bottom diagram). Thereafter, this roll position is maintained throughout the entire cast with little or no re-adjustment.

The ease with which the billet straightens under its own weight on to the roller track depends on the resistance of its section to bending, and this can be reduced effectively by maintaining adequate temperature.

Fig. 17—Preheating of ladle and two tundishes in progress on twin-strand machine

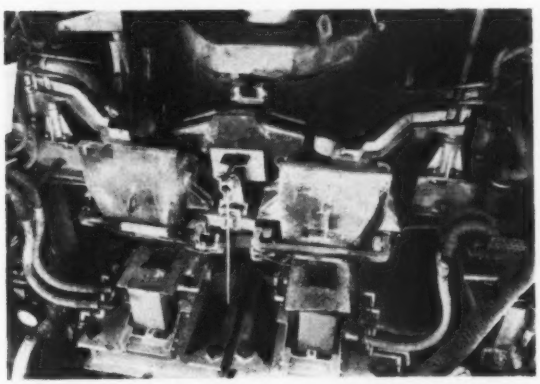

Fig. 16—Assembly of equipment above the two moulds of the twin-strand machine showing two tundishes complete with individual combustion can heaters and transverse tilting launder used to split the supply of metal from the lip of the ladle

Fig. 18—Rear view of tilting launder and tundishes on twin-strand machine showing slag overflow notches and triangular slag boxes

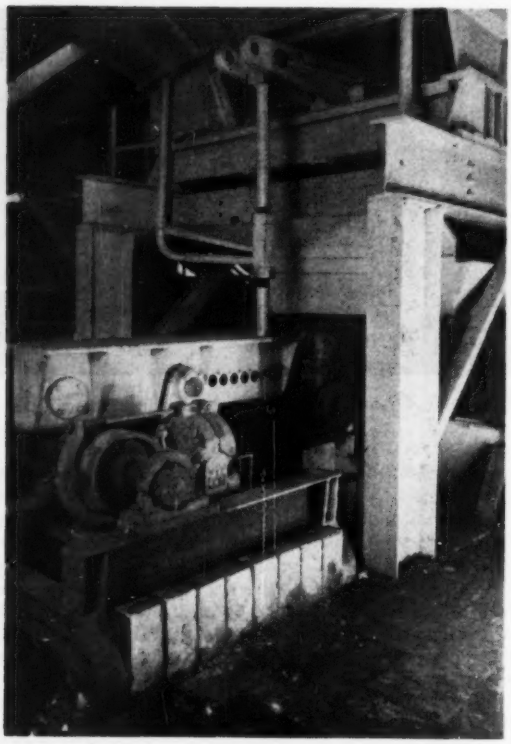

Fig. 19—Reciprocating cam, sway beam and brake, and part of link system on twin-strand machine

Usually the billet is sufficiently hot to emerge horizontally along the roller track, but, in certain cases, it is necessary to aid straightening and for this purpose the straightening roll stand is provided. In this a vertically movable roll, carried on a screw or power-cylinder piston, is positioned over the discharge roller track. Only when necessary is this roll lowered on to the upper face of the billet to help straighten it.

Power for bending and for horizontal discharge is derived solely from the withdrawal rolls, the bending and straightening rolls being free to rotate with the billet. The bending rolls are flanged, but not the straightening roll, and the radius of bend is about 8 ft 6 in.

Manual or mechanized cutting of the billet may be employed as it moves along the roller track and the cut billets can be discharged in the usual way on to orthodox-type hot banks. At Barrow, 30-ft billet lengths are regularly produced, but billets up to 150 ft long have also been prepared and short lengths can, of course, be cut as required. The general view in Fig. 13 of the single-strand machine at Barrwo, taken in August, 1956 whilst casting 3-in. square billet, shows the billet descending through sprays and withdrawal rolls, and discharging along the roller track where manual cutting is in progress. The thickest section delivered by bending so far is 3⅝-in. square billet; 6-in. × 2-in. slab is bent to discharge on the broad face.

Twin-strand machine

On the twin-strand machine the ladle is arranged to lip-pour into a transversely held launder, from which two metal streams emerge to feed tundishes on either side. Each tundish nozzle pours into a separate mould supported on its own mould table and reciprocated by its own cam-and-link system. The billet emerging from each mould descends through water sprays to a pair of withdrawal rolls. Below the withdrawal rolls the two billets are independently bent to discharge horizontally along individual roller tracks to cut-off stations and hot banks. The two strands have independent drive machinery and are separately controlled, in each case a single main-drive motor serving to rotate the withdrawal rolls and operate the cam system. Thus, apart from the common ladle and transverse launder, virtually two casting machines are built side by side.

Figure 14 shows diagrammatically the arrangement of the main parts of the twin-strand machine, the view being a front elevation. The 7½–8-ton ladle, complete with lid, is again placed in the tilting cradle at the top of the machine and the small launder mounted transversely in front of, and below, the ladle lip is pivoted at its centre so that it may be tilted to either side. Normally, however, it is held approximately in the horizontal position by an oil-powered control cylinder fitted immediately below it. The function of the launder is to split the supply of metal from the ladle into two separate streams which pour over lip-bricks built into the ends of the launder. Figure 15 shows some of the detail of the launder. The central portion of the launder is deeper than the

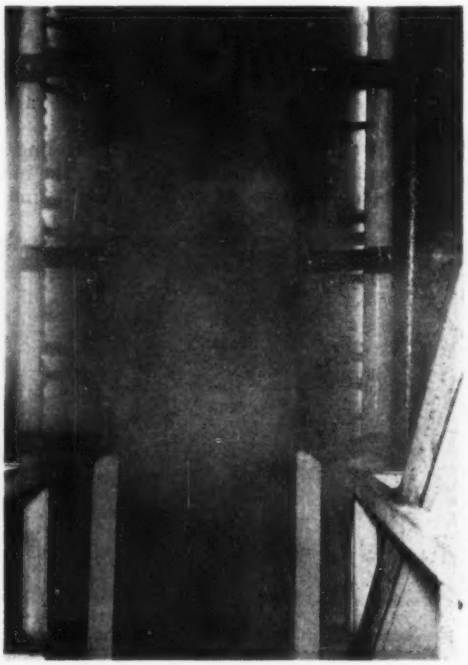

Fig. 20—Billets descending through spray zones during casting on twin-strand machine

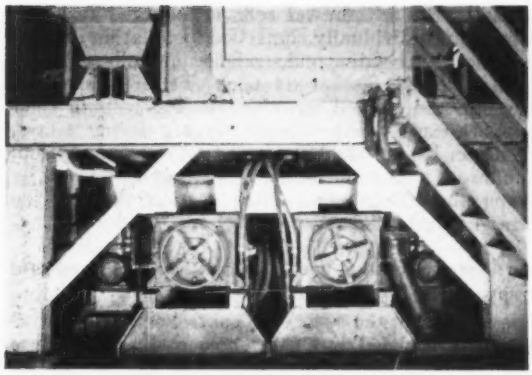

Fig. 21—View of withdrawal roll housings from rear, showing load-setting handwheels and water catch-pan and drain on twin-strand machine

Fig. 23—Close-up view of billets emerging from movable bending rolls during casting on twin-strand machine

sections across the lips where the metal overflows, so that metal from the ladle lip forms a pool before overflowing down the east or west pouring lips. In addition, these lips themselves are set at an angle so as to impart to the discharging metal sufficient velocity to maintain reasonable trajectories in delivery. The launder is in fact supported on a small tilting frame for easy replacement between casts. The angle of tilt of the frame is controlled by the ladleman, using a lever-valve in circuit with the oil-powered cylinder beneath the frame.

The two tundishes, into which the launder discharges from its ends, are supported side by side just below the launder. Sufficient angle of tilt is afforded to cause all the metal discharging from the ladle lip when casting to pour in either direction and to interrupt completely discharge over the raised end of the launder. The two tundishes and the transverse tilting launder are seen in Fig. 16. The nose of the ladle lid has been cut back somewhat to prevent the lid from making contact with the front splash wall of the launder when the ladle is at maximum tilt towards the end of a cast.

Each tundish is fitted with a small combustion can heater which, separately supported, is able to swing clear for tundish replacement. Figure 17 shows the two tundishes and the ladle being preheated by their respective combustion cans whilst Fig. 18 views from the rear the tilting launder and the tundish heaters positioned over the brick clamps covering the tundishes. Figure 18 also shows the tundish overflow notches and, beneath these, the slag boxes into which slag may overflow should it collect on the metal inside the tundish during casting. These slag boxes are triangular in shape to provide sufficient space for the ladle.

Below the tundishes in Fig. 16 are seen the 2-in. aperture moulds with pipes for propane shielding and for rapeseed oil. Each mould is mounted on its own mould table which, as indicated in Fig. 14, is reciprocated by its own cam-and-link system. One of the reciprocating cams is seen in Fig. 19, together with sway-beam and link connecting to the rocker arm, which at its other end is linked to the mould table. The alternative holes in the sway-beam and rocker arm allow different lengths of mould reciprocating stroke to be obtained. On the cam shaft is fitted a standard electromagnetic brake

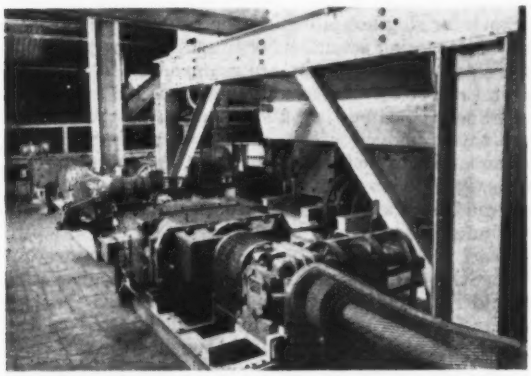

Fig. 22—View of main drive machinery on machinery platform of twin-strand machine

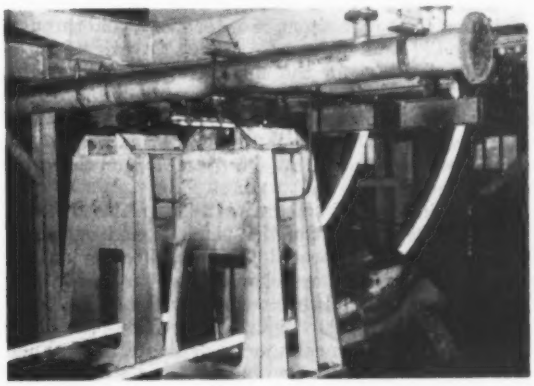

Fig. 24—General view of billets bending to discharge horizontally under their own weight through straightening roll stand during casting on twin-strand machine

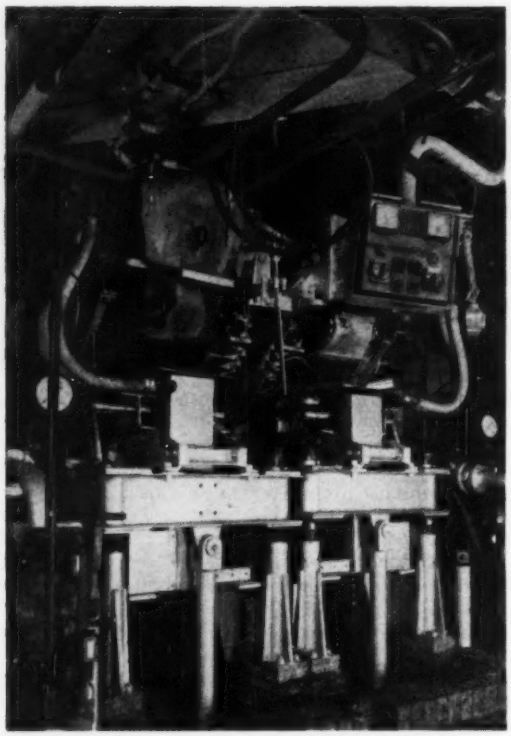

Fig. 25—View of casings housing radioactive sources and photomultiplier tubes used to detect metal level within moulds and also of manual-control pendant on the twin-strand machine

which remains closed until energized. Wired into the main-drive circuit this brake opens on starting the machine and allows the cam to rotate and the mould to reciprocate. If the main drive is switched off the brake closes and movement of the mould is immediately halted. Use of the brake ensures the closing of the mould tube by the dummy bar and prevents any unwanted movement before starting a cast.

As indicated in Fig. 14, the billet descends from each mould through a zone of water sprays and through a 'daffodil' and water catch-pan to a pair of withdrawal rolls. As for the single-strand machine, the water sprays consist of nozzles on pipe frames suspended on chains and able to swing so as to follow slight lateral movements. Figure 20 is a view of the two billets descending through the sprays on the twin-strand machine.

The spring-loaded withdrawal rolls are also identical to those developed for the single-strand machine. The roll housings, located beside each other on the machinery platform, are viewed from the rear in Fig. 21 to show the handwheels whereby the spring loading of each is applied. Figure 21 also shows the water catch-pan and drain common to both strands. Each withdrawal roll is driven again through infinitely variable gears by a 7½-h.p. a.c. motor which also drives the related cam-and-link system. Figure 22 is a front view of the machinery platform, showing the main drive machinery for each strand.

Below the withdrawal rolls is mounted for each strand an individually controlled installation of fixed and movable bending and straightening rolls, together with horizontal discharge tracks. Figure 23 shows in close-up the flanged movable bending rolls in their support frames with billets emerging during a cast, whilst in Fig. 24 the billets are seen descending from the two bending roll units to discharge horizontally along the roller tracks after passing through the straightening roll frames.

Twin-strand casting procedure with automatic control

The twin-strand machine at Barrow is normally operated using the automatic control equipment with which it is fitted but the whole casting procedure can, of course, be carried out under manual control conditions. Below tundish level the two strands operate quite independently except insofar that, mounted on the same structure, they derive their metal supply from a common ladle via a transversely tilting launder. Operating procedure under manual control conditions is thus essentially similar to that for the single-strand machine as far as preparatory duties and casting operations below tundish level are concerned. Starting procedure in regard to the initial delivery of metal to the tundishes is different.

Casting, of course, begins only after the desired temperature for the metal in the ladle has been confirmed by immersion pyrometer. The ladleman controls the tilt of the ladle using the valve in circuit with the cradle-lifting cylinders. He is provided with a casting-speed indicator for each strand and, as far as possible, he maintains similar speeds on both strands by balancing the tilting launder, using the valve in its control cylinder circuit. By adequately tilting the ladle the required casting speed on both strands is thus obtained.

For various reasons, but particularly to secure complete removal of the slag which issues from the ladle lip with the first flush of metal and to ensure trouble-free discharge of metal initially through the nozzles of each tundish, it is preferable to start pouring from the ladle with the transverse tilting launder held approximately in its horizontal position. The initial flush of metal and slag then pours over the lips at both ends of the launder at practically the same time, and these initial streams are diverted into the triangular slag boxes behind the tundishes by manually interposing semicircular troughs below the launder lips. These troughs are removed as soon as the metal runs clear of slag and this condition is reached at about the same time at both ends. Both troughs are thus removed within a very short time of each other and the metal streams from the launder pour directly into the tundishes, establishing metal discharge from their nozzles at practically the same time.

Under manual control conditions, starting procedure at each mould would be as described in connection with the single-strand machine. An index wire would be hung in each mould and observed through an angled mirror, each strand being started as the rising pool of metal in the mould touched the wire and, thereafter, machine speeds would be adjusted to balance the rate of discharge from the tundish nozzles.

This starting procedure would require two mould operators, one at each mould, and it is doubtful whether, even after casting has been established on both strands, one operator could control both machines with sufficient reliability to meet production requirements. The need for two operators pertains particularly to the twin-strand casting of small sections at high speeds under manual control conditions, the position being rather different for the casting of larger sections, say, 3½ in. square and upwards.

The use of automatic control as developed at Barrow introduces a large measure of simplification in the running of the twin-strand machine particularly in regard to the starting operation. Although lacking detail because of pending patents, the outline which follows should suffice to show the method of operation and the advantages afforded.

In addition to manual controls each strand is fitted with automatic control equipment to regulate casting speed. Basically, the metal level within the moulds is detected by means of γ radiation transmitted through the mould walls from shielded and collimated radioactive sources such as cobalt 60 or caesium 137. Photomultiplier tubes positioned on the opposite side of the mould casings receive the transmitted radiation. The amount of radiation detected depends upon the height of liquid steel within the mould. Thus, if the metal level is low a high signal is obtained.

Figure 25 is a general view of the moulds mounted on their mould tables with the γ-ray sources and detectors installed inside protective metal casings. The detection units inside the casings are mounted on fixed brackets below the mould tables and project upwards through the support frames. Whilst the mould assembly and tables are reciprocated, the detection equipment does not move, which is advantageous since the metal level within the mould requires preferably to be controlled to a given suitable height above ground level consistent with the level not being so near either the top or bottom of the mould as to risk metal overflowing the mould or the newly cast billet wall being pulled out from the bottom of the mould tube.

The detection equipment at each mould transmits two signals, proportional to the height of metal in the mould. One signal is used to provide an indication of metal level on the manual control pendant (seen in Fig. 25) to aid changing from manual to automatic operation during casting. The second signal is transmitted to the automatic regulating equipment, where it is chart-recorded and used to effect control. The automatic control equipment responds to the magnitude of this signal, comparing it with the magnitude of the signal which is, or would be, obtained with the metal level at a chosen or given height for control. Depending on the resultant difference, the control unit makes appropriate changes in the rate of billet withdrawal from the mould. As is done by the mould operator using the change-speed lever under manual control conditions, the control unit effects an increase in billet withdrawal rate should the metal level, as detected by the γ-ray equipment, be above the chosen control point and, likewise, introduces a suitable reduction in withdrawal rate should the level be below the control point.

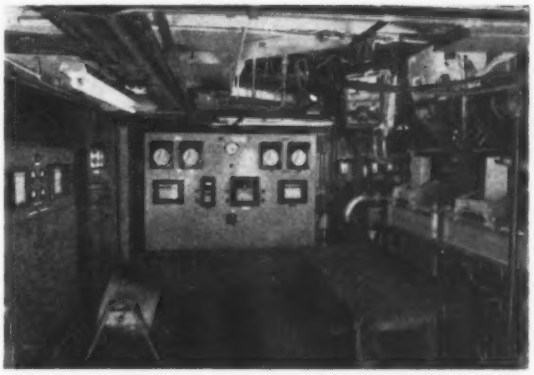

Fig. 26—General view of mould-operator's platform showing casings of level-detection equipment at moulds, manual-control pendant, and panels housing automatic control equipment, recording instruments, and main-drive electrical contactor gear

The pendant combines in one box the controls for the two moulds, but operationally its two halves are quite separate, corresponding to the east and west moulds. On the lower half of each side are placed the 'start' and 'stop' pushbuttons and the change-speed lever for manual operation. Immediately above are sited the 'auto/manual' throwover toggle switches allowing manual operation or automatically controlled operation to be chosen for each strand as desired. When switched down towards the manual controls these switches connect the manual change-speed circuits, cutting out the automatic control circuits, and when switched upwards towards the indicating dials the switches cut out the hand-operated controls and bring into action the automatic control circuits.

The indicating dials and lights at the top of the pendant are referred to when changing from manual to automatic operation should this be desired during casting. The dials indicate metal level within each mould, whilst the lights show that the automatic circuits are in fact energized and operating. It is preferable to be sure that the control circuits are energized before switching them into use and, when doing so, to arrange for the metal level to be reasonably close to the desired control point, thus eliminating disturbance in the operation of the machine. In switching back from automatic to manual operation no reference need be made to these indicators, the toggle switches simply being depressed by the operator as he places his hand on the change-speed lever.

Figure 26 is a general view of the mould-operator's platform showing the moulds, the casings enclosing the level detection equipment, the manual-control pendant and, opposite these, the panel containing the electronic circuits and automatic control equipment for each strand. The instrument panel in the background carries recorders for liquid steel temperature (Tinsley Industrial Instruments Ltd.), casting speed (Elliott Bros. (London) Ltd.), water flow (George Kent Ltd.), and temperature rise in the water passing through the moulds (Honeywell Controls Ltd.). The panel between that housing the automatic control

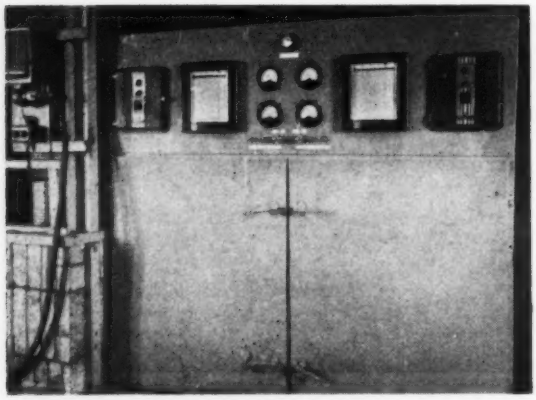

Fig. 27—Front view of panel housing electronic circuits and automatic control equipment with charts showing records of metal level for second half of cast on twin-strand machine

equipment and the recording instruments contains the electrical contactors and associated equipment for the main drives and other primary operating units.

Figure 27 shows the panel housing the electronic circuits and automatic control equipment for the east and west strands. Use has been made of standard recorder and control units marketed by Integra, Leeds and Northrup Ltd., suitably modified to meet requirements.

The scales of the recorders correspond to the total mould lengths over which the γ-ray sources and photomultiplier tubes operate, namely 15 in., the upper limit being 4 in. and the lower 19 in. from the top of each mould. Each recorder has two indicating pointers; the lower one moving with the recording pen follows the variation of metal level in the mould, whilst the upper one is the 'set' pointer and may be moved over the whole scale, but is positioned beforehand to the level at which it is desired to maintain control, usually at about 75% up the scale. The control level is thus usually set about 7 in. below the top of the mould, or about 3 in. below the top of the detection range. The control action provided by the equipment is based upon a function of three control 'terms' or controlling actions, namely proportional action, integral action, and differential action, and the equipment is calibrated to make appropriate changes in the withdrawal speed so as to maintain the metal level as far as possible close to the prechosen control point or level. In Fig. 27 the record for the latter half of a cast can be distinguished, and it will be seen that the general level maintained is quite constant, although small fluctuations occur continually. These fluctuations, in terms of metal level within the mould, have an amplitude of $\pm \frac{3}{8}$ in., even with casting speeds as high as 360 in./min.

The speed of response, although not as yet fully developed, is already quite adequate. Thus, the equipment has been found capable of maintaining metal level under conditions where blockage of the nozzle has occurred, as a result of which the casting speed has been reduced to about 50 in./min. When the blockage suddenly cleared itself, so that the nozzle immediately began to discharge again at full bore, a change corresponding to a sharp step-up in casting speed to about 260 in./min, the metal level rose only to about 1 in. above the control level and at once subsided into the normal band of fluctuation. The response speed is also quite adequate to cater for the conditions pertaining both at the end and start of a cast.

At the start of a cast, the speed of the withdrawal rolls is pre-set to about two-thirds the expected casting speed and the automatic control equipment is then energized and prepared for operation. When the nozzle stream is established, the metal level rises into the detection range, and this is indicated by the initial movement of the lower pointer. If the operator switches-in the main drive motor as the pointer moves up the scale the control action is such that the metal level is allowed to rise to the control level and normal regulation is then established. A similar result occurs if the operator instigates withdrawal when the rising level within the mould reaches the control level, as shown by the lower pointer moving up to the position of the upper pointer. In this case the level rises slightly above the control level and is brought back almost at once into the normal fluctuation band. Moreover, at the end of a cast, when the metal drains from the tundish and the nozzle discharge suddenly changes from metal to slag, the control equipment slows down the withdrawal rolls and may well stop the machine whilst still holding the metal level at, or just below, the control point. Incidentally, at the end of a cast the operator inserts the end of a bent copper pipe up the bore of the nozzle as soon as slag begins to discharge, so allowing run-out of the final portion of billet in the machine to proceed immediately.

The usefulness of the automatic control equipment has been greatly extended by the addition of extra circuits which, at the start of a cast, automatically switch on the main drive units to initiate withdrawal of the billets from the moulds. These so-called 'self-start' circuits are relatively simple and extremely reliable, and greatly simplify the general starting procedure. Under self-start conditions the operating procedure is as follows:

> As soon as the required metal temperature in the ladle has been confirmed, and the mould tops for each strand have been cleared, water flow to the moulds is turned on and tilting of the ladle is begun. The transverse launder is placed in an approximately horizontal position and, when metal begins to flush from the ladle lip, the semi-circular troughs are inserted below each end of the launder to divert the slag-bearing metal into the slag boxes. When the metal discharging at each end of the launder runs clear of slag the troughs are removed quite independently of each other.
>
> As metal enters each tundish and initiates discharge through its nozzle, the metal begins to rise in each mould and the self-start circuits appropriately switch-in the main drives of each strand so that extraction of the billet begins. Thereafter, the level of metal in each mould is rapidly brought to the control point and casting continues at this level. On starting, the rapeseed oil drip-supplies

to each mould are also begun, whilst propane shielding of the nozzles and water supplies to the spray units are also started either automatically or manually.

The ladleman adjusts the position of the transverse launder to obtain approximately similar casting speeds on both sides and makes appropriate increases in the lift of the ladle to achieve the required level of casting speed. Meanwhile, at ground level, the two cut-off operators remove the dummy bar lengths and proceed to bend the billets to horizontal discharge.

The mould operators are only required to check that the automatic control units were in fact energized before starting to pour and were still indicating certain check readings which, because of the reliability of the equipment, are unlikely to have altered. In addition, they switch-in the self-start circuits a few moments before delivery of the metal to the launder is begun. They then stand by and, as pouring begins, each strand starts itself as described and continues to cast under the control of the automatic equipment so long as metal is delivered from the tundish nozzle. When slag begins to discharge, each strand brings itself to a halt, at which time the operators block the nozzles with their bent copper tubes, immediately switch over to manual control and run out the remaining lengths of billet from the machine at constant speed.

For safety reasons, the operators switch out the self-start circuits shortly after casting begins. In fact these circuits are at all times kept switched out, except for the start of a cast. This is made a strict rule because the circuits are so certain to operate that if not switched out they introduce a strong element of danger when maintenance operations, particularly electrical maintenance, are being undertaken between casts, and when operational check tests are made preparatory to running. To ensure that this safety measure is adhered to, the self-start circuits can only be switched-in by Yale-type barrel switches, and only the mould operators are issued with keys. The Yale-type switches are seen beneath the indicators in the centre of the control panel in Fig. 27.

The use of automatic control equipment, and particularly the self-start circuits, greatly simplifies the operation of the machine. No time correlation need be considered in regard to which strand is started first and both strands may be started with only one operator or possibly none at all standing by, although as yet this has never been done. Under production conditions one mould operator would still probably be required to check that correct conditions at the moulds are maintained, and in case of emergencies.

TABLE I

Main dimensions of twin-strand casting machine at Barrow Steel Works Ltd.

Casting size specifications	
Square billets	**2–4 in.**
Slab sections	**6 in. × 2 in. up to 12 in. × 3 in.**
Ground level heights to:	
Crane hook	**46½ ft**
Ladle pouring lip	**32½ ft**
Mould top	**29 ft (approx.)**
Withdrawal roll centre-line	**11 ft**
Fixed bending roll centre-line	**9⅞ ft**
Movable bending roll centre-line	**6½ ft**
Mould length	**32 in. (approx.)**
Distance between mould centre-lines	**42 in.**
Maximum height available for spray cooling	**13 ft (approx.)**
Length of spray cooling zone used	**8½ ft (approx.)**
Bending radius	**8½–9½ ft**

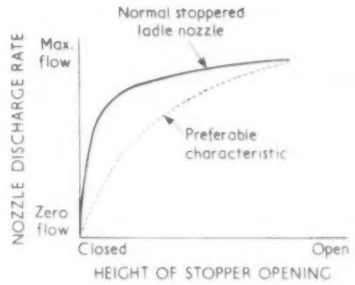

Fig. 28—Sketch of typical discharge characteristic of stoppered ladle nozzle compared with characteristic preferred for control of ladle-nozzle discharge in continuous casting

Casting machine dimensions

The main dimensions of the twin-strand machine installed at Barrow in May, 1958, are shown in Table I. The machine is designed to twin-strand billet sections up to 4-in. square and slab sizes up to 12 in. × 3 in. These larger sizes have not, as yet, been cast, but it is hoped to undertake trials in the near future.

Although casting speeds are high, the machine is not a tall one, the distance from ground level to mould being only about 29 ft. Moulds are about 32 in. long and the spray cooling zone is only about 8½ ft, although the height available for spray cooling is about 13 ft. The main dimensions and power of the bending equipment, through which 3⅜-in. square billet has been the thickest section discharged to date, are considered adequate for bending the larger sizes, namely, up to 4-in. square billet and 12-in. × 3-in. slabs.

Performance data

Operational features and performance data pertaining to the Barrow process are summarized in Table II. Figures for the standardized procedure established under routine works conditions are listed, together with comments and data from relevant performances in experimental runs. Except where stated, the quoted figures refer mainly to the casting of carbon steels in the range 0·05–0·80%C.

The data applies to both single-stranding and twin-stranding operation, the only real difference in this respect being in the tapping temperatures. When twin stranding the use of the transverse tilting launder introduces an extra pouring operation. Because of this, and because the launder is not preheated, the metal suffers an extra temperature drop during its discharge from the ladle into the tundishes and it has been found preferable, when twin stranding, to start casting with the metal in the ladle at a temperature about 20° C higher than for the same quality when single stranding. Hence ladle preheats are sometimes slightly greater for twin stranding,

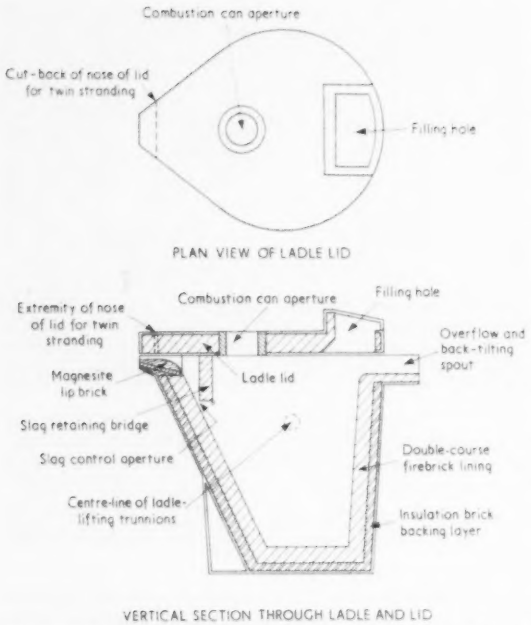

Fig. 29—Diagrammatic features of lip-pour ladle and lid

and furnace tapping temperatures are generally also taken about 20° C higher than for single stranding.

LIQUID METAL HANDLING

Control of metal flow and maintenance of metal temperature are the important factors in supplying liquid steel to a casting machine and, for both considerations, the aim is to minimize loss of yield.

Chemical changes in the metal are negligible for pouring periods up to about 1¼ h. A small manganese loss occurs progressively and, whilst this is of no consequence in normal running times of up to 1¼ h, it may become noticeable over appreciably longer casting periods approaching 2 h or more. Under these circumstances, however, the loss is not large and, although no work has been done in this connection, corrective measures seem possible.

Use of lip-pour ladles

Lip-pour ladles were adopted because they allow the use of high preheat and provide greater control of the rate of metal discharge. Stoppered ladles cannot be preheated to the same extent because of the risk of weakening the stopper. Preheating of stoppered ladles could be carried out before fitting the stopper, but the procedure for fitting the stopper into a hot ladle is not easy and long casting periods present difficulties.

Also significant is the lack of control of metal discharge associated with a nozzle-pouring ladle. Discharge rate is essentially determined by the bore of the nozzle and the head of liquid metal above it. As the ladle empties the rate of discharge tends to reduce unless the material of the nozzle is such that its bore gradually enlarges at a rate compensating for the effect of reduced metal head. At any time during emptying, however, the control permitted depends on the discharge characteristic of the stoppered nozzle, considered simply as a flow-control device. A typical discharge characteristic for a given head is sketched in Fig. 28. When the nozzle is nearly closed by the stopper, a small change in stopper height causes a large change in the discharge rate through it; when almost fully open, a large movement of the stopper only alters nozzle discharge by a small amount. Control of nozzle discharge is thus only practical for almost full-bore conditions or, more precisely, from about 70% to 100% of rated discharge.

For a full ladle fitted with a given stopper and nozzle the discharge would be at a relatively high average rate with limited control at this high level. During emptying, the average rate of discharge would decrease progressively and, likewise, the control range in terms of actual discharge, no allowance being made for bore enlargement. Generally, control of metal flow would be limited for continuous casting purposes and casting speeds would tend to be appreciably lower towards the end of a cast than at the start. The control problem is rather easier for large sections.

A flatter, more gradual characteristic, such as indicated in Fig. 28, would of course allow control over almost the full range, and it would be possible to adopt a nozzle size allowing fairly constant casting speeds to be maintained throughout a cast. Unfortunately, a practical stoppered nozzle design of this type does not, as far as is known, exist. A lip-pouring ladle has a relatively flat characteristic against axes referring, of course, to discharge rate and angle of tilt and, as is known, control of the flow is possible to any desired average speed.

The ladles used at Barrow are of a ' semi-teapot '

Fig. 30—View of bricked lining and of slag bridge in front of the pouring lip of 7½-ton ladle

design and, as seen in Fig. 29, are fitted with a 15-in. deep slag bridge, built transversely in front of the pouring lip. The construction of the slag bridge in relation to the lip and the lining is shown in Fig. 30. The wall of the ladle slopes up to the pouring lip and the aperture between it and the bottom edge of the slag bridge is about $\frac{3}{4}$ in. $\times$ $5\frac{1}{2}$ in. wide. This design effectively holds back the slag during pouring (apart from the initial flush of metal which is disposed of), and allows drainage of all metal and slag at the end of a cast. The $\frac{3}{4}$ in. dimension is a maximum and the ladleman has instructions not to accept the ladle for service if this dimension is greater than specified. Figure 31 is another view of the ladle, showing the aperture and lip. The tilting axis coincides with the outer end of the ladle lip and the maximum angle of tilt is 56°.

The ladle lining has always consisted of two brick courses arranged so that the joints are 'broken' in the radial direction. This lining is usually of good ladle-quality firebrick. The inside course, which is 3 in. thick, is patched or renewed when necessary, the outer course, only $1\frac{1}{2}$ in. thick, being semi-permanent. These two courses are backed by a permanent lining of high-temperature insulation brick, usually 3 in. thick. The bridge is always constructed of ladle-quality or high-alumina firebrick and the ladle lid is similarly lined, the ring bricks of the burner aperture and the facing bricks of the filling hole being invariably of high alumina. The use of high-alumina firebrick for lining the ladle itself has recently been found to show some benefits, but the matter is still under review.

The lining of the transverse launder, used for twin stranding, is simply of standard fireclay bricks with shaped pouring lips made to a similar but foreshortened pattern as that of the ladle lip.

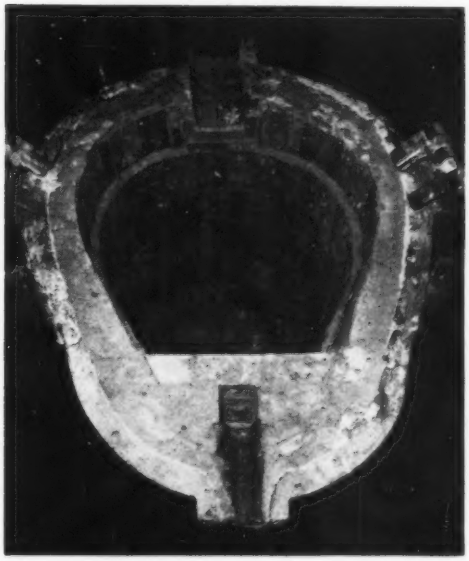

Fig. 31—View of pouring lip and gap behind slag bridge of 7½-ton ladle

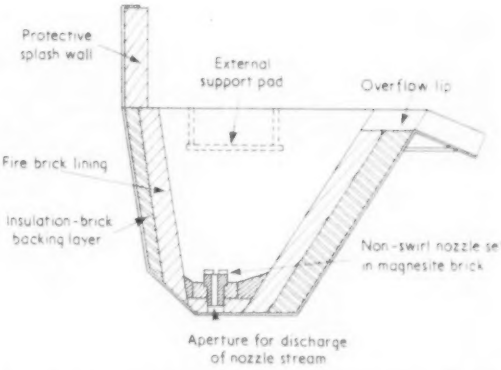

Fig. 32—General arrangement of tundish and non-swirl nozzle for twin-strand machine

Tundish and nozzle construction

As shown in Fig. 32, the tundish has a simple box-like design with sloping walls. No weirs or brickwork skimming devices are included and the pouring nozzle carried in the floor allows complete drainage of metal at the end of a cast. The tundish is lined with ladle-quality firebrick, usually 2 in. thick; this is replaced before each cast and is backed by a permanent lining of high-temperature insulation brick, also about 2 in. thick.

The nozzle, usually made of zircon or zirconia, is of a special non-swirl design first suggested by the author (1951) and developed at Barrow. As shown in Figs. 32 and 33, the head of the nozzle, which protrudes slightly above the floor of the tundish, includes a number of transverse slots which provide passages for lateral flow of the metal to reach the bore. These lateral flows eliminate the effects of any swirl velocities which may occur in the metal pool above the nozzle. As a result, the nozzle discharges a vertical rod-like stream of metal virtually free of swirl. The use of non-swirl nozzles largely ensures the clean pouring of metal into 2-in. square aperture moulds at rates, to date, of up to 15 tons/h, even with a metal 'fall' height of about $13\frac{1}{2}$ in. In addition, a relatively quiescent metal meniscus results within the mould and makes for improved surface in the cast product. The bright meniscus edge of the metal in the mould observed in Fig. 34 is typical of the quiescent conditions which result.

Figure 35 shows the construction and lining of a tundish, complete with a mounted nozzle. This tundish has a capacity of about 450 lb of metal, that used previously on the single-strand machine being about 700 lb. In use, the tundish provides a trap for non-metallics in the metal and slag which drains from the ladle towards the end of a run. These unwanted materials float on the metal pool in the tundish and, if excessive, can escape via the overflow lip.

The bore of the nozzle is chosen according to the section being cast and the desired casting speed. Thus, for 2-in. square billets cast at speeds up to 300 in./min. a $\frac{17}{32}$-in. bore nozzle is used. The maximum metal head afforded by the tundish is 14 in., a head of 10–12 in. being typical for speeds of

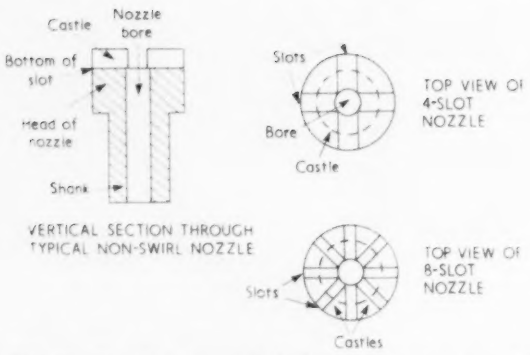

Fig. 33—Sketch of general design of typical non-swirl nozzles

about 260 in./min. For 3-in. square billets, $\frac{9}{16}$-in. bore nozzles are usually mounted in the same tundishes. In Fig. 32 the nozzle is shown mounted in a recessed brick with a circular aperture to take the nozzle shank. The support brick is of chrome–magnesite, about 2 in. thick, and rests on a suitably cut $1\frac{1}{2}$-in. thick insulation brick. The chrome–magnesite brick is rammed into position in the floor of the tundish, using raw ganister. Though a somewhat odd combination of refractories, the arrangement works well.

The nozzle materials, zircon or zirconia, are not ' wetted ' by liquid steel. Other apparently suitable refractories, such as sillimanite, have not proved so successful because of their tendency to ' wet '. Thus, a sillimanite nozzle of standard design produced a stream which tended to ' pull ' or diverge from the vertical, the direction of divergence changing slowly.

Zircon nozzles mainly are used and give satisfactory service. Work has been proceeding in recent years towards standardizing the quality of zircon nozzle supplies and nozzles in this material are being produced to a fairly close specification. At present the specification is tentative, but promises to be a means of ensuring correct refractory properties and therefore reliable performance.

Zircon, however, has little resistance to iron oxide (FeO), and care is required when preheating zircon nozzles to prevent any scale coming into contact with them. The effect of FeO on zircon at temperature is to weaken it so much that a nozzle deforms or fractures at the affected part on taking metal. As a result, it may become blocked at the upper end of the bore. The low resistance of zircon to FeO attack also applies to attack by MnO. As a result, difficulties may be experienced when pouring high-manganese steels; the nozzle soaks up the traces of MnO in the metal and, during a cast, gradually weakens. Similar effects are expected to occur with rimming steels.

The development of a nozzle material resistant to iron oxide is therefore important. Nozzles fabricated in zirconia of excellent quality can be obtained from the U.S.A. Stabilized zirconia has good resistance to iron oxide and in other respects is satisfactory, but the production of zirconia nozzles of suitable quality and at suitable price is difficult in the U.K. at present. Work proceeding on the development of good-quality magnesite nozzles is thus of considerable value.

Preheat theory and practice

The aim is to conserve heat in the metal as far as possible between tapping it from the furnace and its

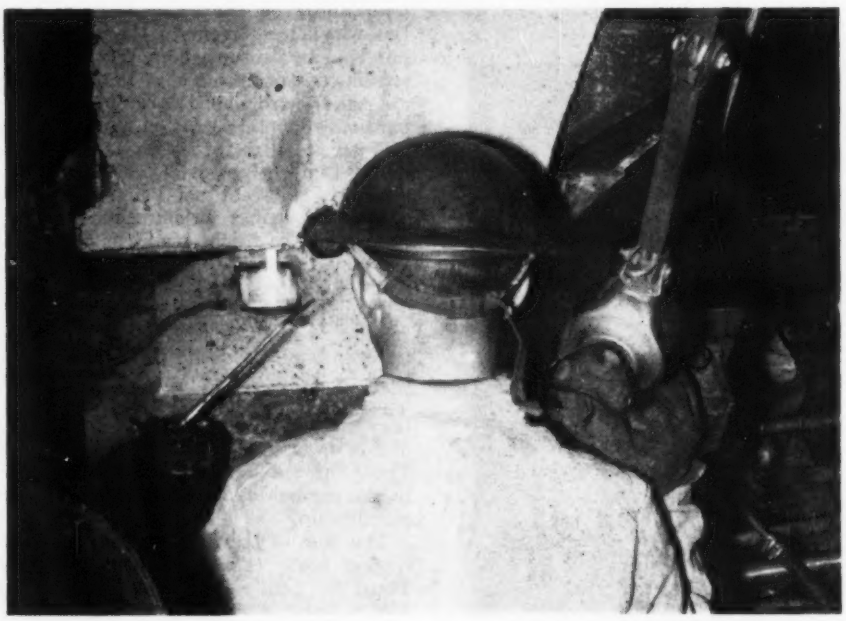

Fig. 34—Photograph of typical quiescent metal meniscus in mould during casting with non-swirl design of tundish nozzle

discharge through the tundish nozzle. Thereafter, heat is removed from it as rapidly as possible. Insulation of the ladle and tundish walls reduces heat losses by conduction. Preheating of these receptacles is adopted to minimize the ' heat capacity ' of the walls by establishing within them temperature gradients approximating to those which might be expected to exist after a period of contact with the metal. Without preheating, the metal itself has to raise the temperature of the brickwork and continues to supply heat at a higher rate until the gradients are established. By preheating beforehand, the thermal gradients already exist and cooling of the metal is minimized.

For a small-capacity cold ladle the ' wall capacity ' effect is relatively large and fairly heavy skull formation will result unless the metal is supplied with a high degree of superheat. The effect is appreciably mollified with increase in ladle size, but established suitable temperature gradients eliminate these various effects almost entirely.

During the early trials it was at first puzzling to find that the temperature of the metal discharging from the oil-fired ladle towards the end of a run was almost the same whether the run continued for a long period or only a short time. A mathematical analysis was therefore made in 1956 of the conditions affecting metal temperature when holding and when pouring from a lip-pour ladle. Relatively simple summarizing equations were obtained and a similar analysis made on the conditions affecting the thermal operation of a tundish yielded almost similar results.

For the discharge of metal from a preheated ladle the following condition is obeyed:

$$\frac{\phi}{\phi \text{ initial}} = \left(\frac{W}{W \text{ initial}}\right)^{\frac{P}{w}}$$

where ϕ = temperature of metal relative to preheat temperature, W = weight of metal remaining in ladle, w = average rate of pouring, P = thermal constant for pouring, and the suffix ' initial ' refers to conditions pertaining in the ladle when full of metal and about to start pouring.

This analysis takes into account all practical variables and, as far as is known, has not been made before. It will, however, require to be published elsewhere. Two main conclusions were drawn. First, whatever is done in regard to preheat or metal temperature before the start of a cast, the temperature of the metal towards, or just before, the end of a cast will approximate to the ambient preheat temperature. Hence, to ensure minimum loss of yield, the most certain condition is to arrange for the ambient preheat temperature to be just above the liquidus temperature of the metal being cast. This is the basis of preheating practice at Barrow. Second, if the ambient temperature of the ladle, oil-fired throughout the cast, is just above the liquidus temperature of the metal being cast, then it is possible with any given size of ladle to continue casting for any desired length of time, provided metal remains in the ladle. This, of course, implies no extra loss of yield over an appreciable range of average pouring rates. Thus, by fitting special small-bore nozzles in the tundish it was proved possible to single strand for a period of

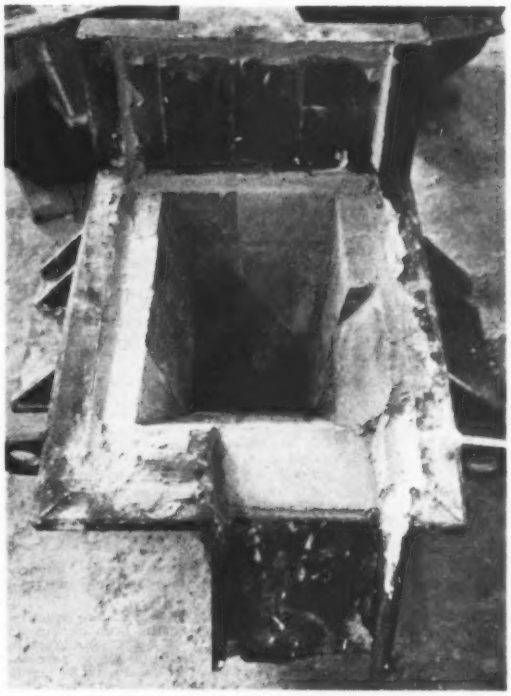

Fig. 35—Construction of tundish complete with mounted non-swirl nozzle as prepared for use on twin-strand machine

up to 2 h from a 7½-ton ladle (an average rate of under 4 tons/h) and suffer no extra loss of yield. This result contrasts with views expressed elsewhere that 1 h is about the limit of casting time and that the casting rate should then be at least 10 tons/h.

Reference has already been made to the strict control of metal tapping temperature, tapping time, and metal temperature in the ladle before casting, and pertinent details are given in Table III. Temperatures of operation are invariably related to the theoretical liquidus temperature of the metal being processed and, as examples, some typical operating figures are shown in Table III.

The ladle and the tundishes are each fired during preheating and during casting by special oil burners developed by The United Steel Companies Ltd. and at Barrow, and designed on principles similar to those pertaining to combustion cans for jet aircraft. About 28 gal/h and 8 gal/h of medium or light-grade oils are used to fire the ladle and tundishes respectively, but heavy bunker qualities can also be used. Preheating of the ladle and tundish is usually continued for about 2½ h before casting to allow heat to soak into the brickwork and establish the wall temperature gradients. Under production conditions the preheating period could be reduced somewhat and probably also the average rates of oil consumption. Certainly, for larger-sized ladles consumption of oil is unlikely to rise in proportion to the tonnage. Hence the quoted consumptions, although somewhat heavy, are likely to be improved

TABLE II
Performance data on Barrow continuous-casting process

Feature	Standardized procedure	Comments
Casting speeds	Routine casts: 220–300 in. min (2-in. billet) 140–190 in. min (3-in. billet) 80–110 in. min (6-in. × 2-in. slabs)	Maximum speeds respectively to date: 360 in. min 200 in. min 150 in. min (In special trials 2-in. billet was cast up to 450 in. min average with 570 in. min maximum)
Corresponding tonnage rates	6½–8½ tons h (2-in. billet) 9–12½ tons h (3-in. billet) 7½–10 tons h (6-in. × 2-in. slabs)	10 tons h (max) 12½ tons h ,, 13½ tons h
Tapping temperature	At least 30° C and 10° C respectively lower for single and twin stranding than in orthodox steelmaking	Probably as much as 100° C lower for certain high-alloy steels. Up to 20° C higher metal temperature required when twin stranding
Ladle preheat temperatures	Single stranding: 1 500–1 540° C Twin stranding: 1 500–1 545° C	Varied with quality of metal. Could be as low as 1 475° C for certain high-alloy qualities
Tundish preheat temperatures	Single and twin stranding: 1 500–1 520° C	Varied only slightly with metal quality
Initial metal casting temperature	Single stranding: 1 570–1 500° C Twin stranding: 1 590–1 520° C (for 0·05–0·80% C qualities)	Depends on quality. Has been as low as 1 460° C for certain high-alloy steels. About 20° C extra preferred when twin-stranding
Casting period	Up to 1¼ h (for 7½-ton ladle)	Up to 2 h proved possible with 7½-ton ladle in slow-running trials
Total length of cast	About 1 330 ft of 2-in. billet	Typical for 7½–7½-ton cast of 2-in. billet. Relatively shorter for larger sections
Discharge cut lengths	Any length up to 30 ft	Hot bank available only limits size. Lengths up to 150 ft have been obtained
Ladle inside lining life	10–13 casts (so far) New ladle lip used for each cast	Improved life expected when ladle design modified
Tundish inside lining life	New tundish lining and nozzle for each cast	Preferred practice
Mould life	2-in. mould: 42 043 ft (235 tons) in 37 casts and still casting as new Other moulds: not known	Latest 2-in. mould design appears to have indefinitely large life
Metallic yield (hot metal to good billet)	About 98% (for 7½-ton ladle) (98·5% overall on 256 tons total produced in 37 consecutive casts)	Even better yield expected for larger ladle charges

upon in a production plant without necessarily departing from the maxim of using high ambient firing temperatures.

This maxim is the main reason, apart from operational reliability of the machine, for the notably high overall metallic yields characterizing the Barrow process. Thus, in the recent reliability trials on the twin-strand machine, 256 tons (45 056 ft) of 2-in. billet were produced in 37 consecutive casts at an overall yield of 98·5%. The fact that metal tapping temperatures for carbon and low-alloy steels are preferably between 10° and 30° C lower than required for orthodox ingot practice (*see* Tables II and III), and for certain high-alloy steels as much as 100° C lower, means that some savings may result at the steelmaking furnaces. Useful savings of power will accumulate for steels made in arc furnaces, whilst with OH furnaces, although the position is rather complicated, small savings of fuel and of production time may well accrue towards the end of furnace life. Corresponding reductions in furnace refractory wear can also be expected.

MOULD OPERATIONS

The solidification process begins with the formation of the 'skin' and 'walls' of the section being cast and the mechanism of their formation takes place entirely within the mould. The section emerges from the mould with a liquid centre and, for reliable performance, it is necessary for mould conditions to maintain stable operation of this mechanism, even at the highest casting speed likely to be encountered. If the operation of the mould is such that the mechanism of wall solidification is disturbed, the emerging wall is found to be fractured in certain characteristic ways and the nett result is that the contained liquid metal escapes through the fracture, causing a 'breakout'.

False wall formation

The first type of fracture encountered in attempts to raise casting speed is a transverse fracture of major severity occurring around the whole perimeter of the billet wall. The occurrence of this fracture is always associated with 'false wall' formation and results in a breakout below the mould which leaves a hollow pipe hanging inside the mould tube. The formation of a false wall begins within one or two stroke-lengths of mould reciprocation below metal meniscus level in the mould.

A 'ring' of newly solidified billet skin remains clinging to the mould faces. Since the conditions initiating the fracture still probably persist, the fracture, once formed, moves down the length of the mould as billet withdrawal progresses. Liquid metal flows into the gap left by the descending billet walls and freezes against the exposed mould faces. Most of the solidification attaches itself to the hanging portion of billet skin which therefore thickens and lengthens down the mould faces, forming a pipe within the mould. When the fracture emerges at the lower end of the mould the liquid metal splashes out, leaving the hollow pipe.

The initiation of this fracture depends on the mechanical strength of the newly formed billet skin. The initial freezing of the skin occurs mainly during

TABLE III
Operating temperatures for three typical carbon steels, using 7½-ton ladles

Steel analysis, %C	Ladle preheat temp., °C	Metal temp. in ladle before starting to cast, °C		Metal tapping temp., °C	
		Single strand machine	Twin-strand machine	Single-strand machine	Twin-strand machine
0·10	1 545	1 565	1 585	1 590	1 610
0·30	1 525	1 545	1 565	1 570	1 590
0·60	1 500	1 520	1 540	1 545	1 565

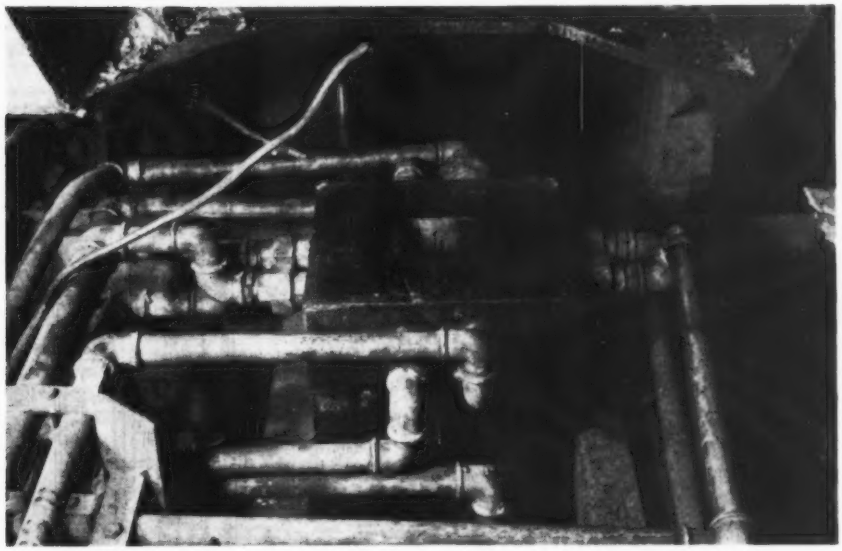

Fig. 36—View of split copper block mould mounted on its mould table as used in early trials at Barrow

the downstroke of the mould under relatively static conditions. On the upward stroke of the mould, however, the skin formed in the previous downstroke is subjected to an upward 'drag' force and, to prevent major fracture, it is necessary for the skin to be strong enough to adhere to the descending billet wall. Drag conditions, of course, arise in all continuous casting processes and are not necessarily more severe with a reciprocated mould. In contrast to other processes, the Barrow principle of mould reciprocation allows the relative drag effects to be minimized.

The strength of the skin formed in the downstroke period depends on a large number of factors. There are factors promoting solidification and high strength in the newly formed skin, e.g. good contact with the mould walls and a high heat-transfer rate through them both by normal conduction and by transient diffusivity effects, whilst the composition of the metal being cast has a direct bearing on the strength of the skin. More highly alloyed steels, such as high-carbon or 18–8 stainless, being stronger at temperature than low-carbon steel, form respectively stronger initial skins and present greater resistance to fracture. Certain factors can cause fracture, particularly the friction or drag of the mould faces on the newly-formed skin, and inversely, the presence or otherwise of a lubricant on the mould faces to reduce this drag. Likewise, the smoothness of the mould faces, and whether they are chrome plated or not, affect drag. Also of importance are metal temperature (if too high the relative amount of solidification is reduced) and casting speed itself. The higher the latter, the shorter the time allowed for initial freezing, although this can be compensated by increasing stroke length for higher speeds.

Of the other factors which play a part, mention need only be made of the method of arranging the mould reciprocation in relation to the descending billet. The mould at Barrow is always made to descend slightly faster than the billet, which method of reciprocation has been called the Barrow principle and is described later under the heading 'Negative strip.' The downstrokes of the mould at speeds slightly faster than the billet cause any solidified material or skin which tends to cling to the mould walls to be carried downwards and be pressed against the descending billet wall, so that the clinging portions are released upwards from the mould faces under compressive conditions. More important, any crack formation which might otherwise be initiated is prevented from forming by the 'closing' action of the mould in relation to the descending billet wall. In fact initial crack formation is, as a rule, completely prevented in this way and by the process of 'compacted crystallization' of the billet skin, which results during each downstroke of the mould.

Mould design

One of the two-piece forged copper block moulds used in the early trials at Barrow is shown in Fig. 36, mounted on its mould table, and its main design features are sketched in Fig. 37. The mould was made in two halves because of the difficulty of machining a 2-in. cavity down the centre of a single block of copper. The two halves mated at a joint along the centre of two opposite faces of the cavity and were bolted together at intervals. The cooling passages were circular holes drilled longitudinally around the cavity, set back about $1\frac{3}{4}$ in. clear of the mould faces and fitted with central baffle rods so as to leave an annular space in each for water flow. The mould was constructed from forged blocks of pure copper, and the cavity faces were chrome plated. The tie-bolts were of steel.

It was in this type of mould that casting speeds of

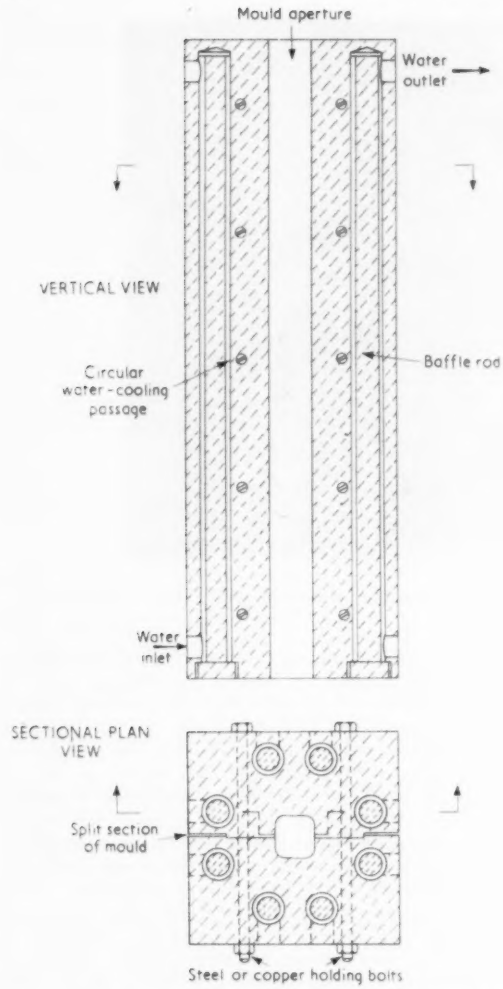

Fig. 37—Sketch of split copper block mould with 2-in. square aperture first tried at Barrow

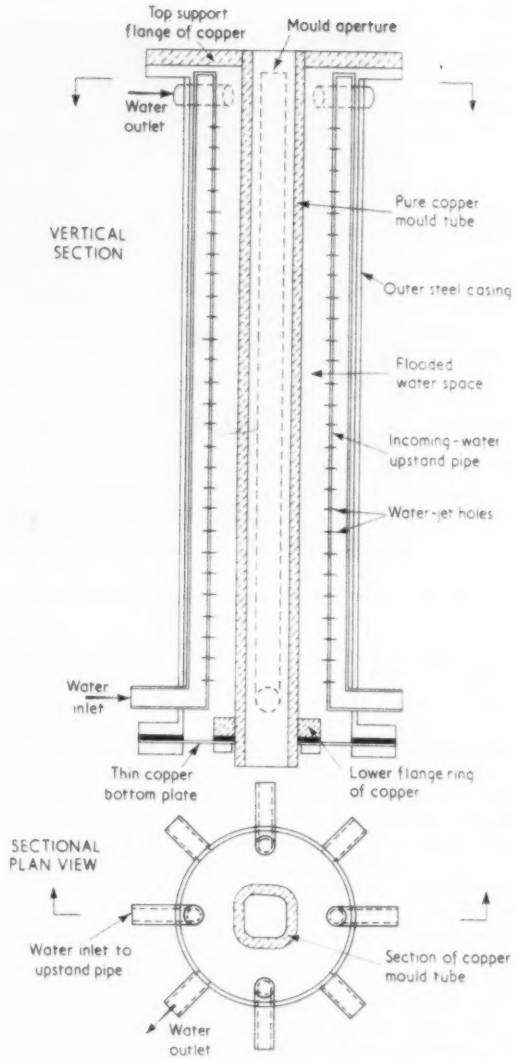

Fig. 38—First design of tubular copper mould tried at Barrow

200 in./min and over were first achieved, but continuous casting could not be maintained mainly because the joint between the two halves of the mould tended to open and allow the liquid metal to form thin fins within the joint. These were 0·009–0·025 in. thick, and often formed to a depth of about 1 in. from the mould face, the average being almost ½ in. Fins were often found attached to the surface of a pipe remaining in the mould at the end of a trial. Casts usually terminated by a breakout leaving a hollow pipe in the mould, owing not to false-wall formation, but to the anchoring action of the fins.

Although the two halves of the mould were most carefully fitted together, this result occurred apparently due to differential expansions. The product from this mould always carried small fin roots on two opposite sides. Eventually a copper block mould with a 2-in. square aperture was produced in one piece, but by then the preference for tubular moulds was well established on the grounds of improved product, heat transfer, and appreciably lower cost. It is doubtful whether the high casting speeds at present averaged at Barrow on tubular-type moulds could be obtained with the heavy block mould because of its lower heat transfer, since the one-piece copper block mould also indicated a tendency to false-wall formation. A typical heat transfer figure for the block-type moulds appeared to be about 740 gal.° C/min, based on about 7° C temperature rise for a water flow of 105 gal/min supplied at about 40 lb pressure.

Figure 38 shows the first design of tubular mould tried at Barrow. The 2-in. square copper mould tube had walls about ½ in. thick with about ½ in. corner radii. A copper flange was brazed to its

upper end to support it inside a cylindrical steel casing. Opposite the four faces were fitted vertical stand-pipes drilled with $\frac{1}{16}$-in. holes at 1-in. intervals up their inner faces, as indicated in the diagram. Its lower end had a copper flange-ring brazed to it and, against this ring and the lower end of the casing, a thin copper diaphragm was fitted to close the bottom of the casing and allow longitudinal expansion of the mould tube. Water at about 40 lb/in^2 pressure was fed to the stand-pipes and jetted through the drilled openings so as to strike the faces of the mould tube. The space around the water jets was kept flooded, the outlets being just below the top flange. The mould tube was chrome-plated inside to a thickness of about 0·004 in.

Overall heat transfer for this mould appeared to be about 30% greater than for the block mould. A typical rate was about 980–1 020 gal.° C/min, based on water flows of about 78 gal/min. The use of $\frac{1}{8}$-in. drilled holes at $\frac{7}{8}$-in. intervals in the upstand pipes made little change. It was also found possible to raise casting speed to about 250 in./min, although false-wall formation tended to occur fairly readily above 210 in./min if conditions were unfavourable. Early trials with negative strip and its adoption as standard practice on 8th January, 1954, however, greatly improved performance by eliminating false-wall formation.

Operations with this mould proved difficult in another respect. At unexpected times, a longitudinal corner crack would occur in the billet wall emerging from the mould, having formed within the mould tube itself. There was some forewarning of its occurrence. The emerging billet would have close to one of its corners (not always the same one) a $\frac{1}{2}$–$\frac{3}{4}$ in. wide re-entrant undulation along its length, the surface of the undulation being much hotter than the rest of the surface, presumably due to loss of contact with the mould faces. The corner crack would occur as a vertical fracture down the centre of the undulation. These fractures varied in length from a few inches to as much as 3 ft, and resulted in liquid metal splashing out and its level within the mould disappearing, so halting the cast. The occurrence of these longitudinal corner cracks was very frequent, even with new mould tubes, and showed no consistent aspects. They could occur just after the start of a trial or towards the end of a fairly good run, and did not appear to be related to casting speed.

A trial was made with a tubular mould mounted in a casing which provided a narrow annular passage around it for the cooling water, the design being similar to that shown in Fig. 39. A 2-in. square mould tube with $\frac{7}{16}$-in. thick walls and $\frac{1}{2}$ in. corner radii was supported by a flange brazed to its upper end in a mould casing of sheet steel, leaving an annular space $\frac{5}{16}$ in. wide. Four inlet pipes supplied water to a distributing box around the steel casing at the bottom and four similar pipes acted as outlets from the collecting box at the upper end. There were considerable delays in preparing the mould for its first trial on 19th February, 1954, and the plate closing the bottom of the water distribution box could only be loosely fitted about the lower end of the mould tube. During the cast, which ran smoothly

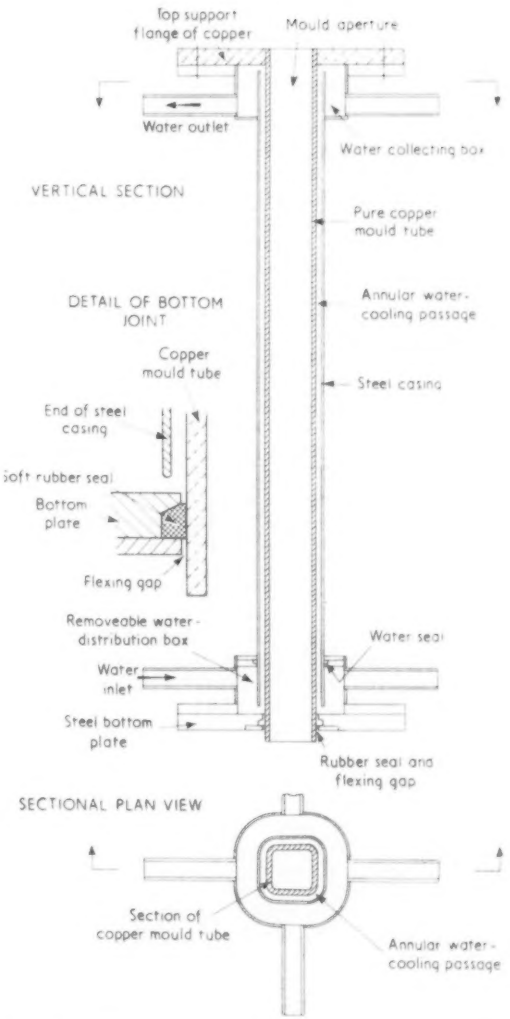

Fig. 39—Main details of tubular copper mould developed and in use at Barrow

until the ladle and tundish were drained empty, it was observed that water was escaping between the bottom plate and the outside of the mould tube. The water, however, escaped in an unexpected manner: it jetted vertically downwards with considerable force from one localized sector on the perimeter of the mould tube, opposite, say, a corner or one of the faces, but the position continually moved round the mould perimeter. It was immediately obvious that the mould tube was in fact moving laterally inside the loose joint, presumably due to some form of flexing of the tube itself during casting. It was also apparent that the previous mould assembly (shown in Fig. 38), restrained lateral movement at the lower end of the mould tube.

For subsequent trials the gap between the tube and bottom plate of the annular-cooled mould was packed with soft rubber rings, as indicated in Fig.

39, so as to allow the tube to move yet prevent the escape of water. The fact that these trials ran without breakouts at longitudinal corner cracks confirmed that lateral movement of the mould tube at one end was a feature essential to the operation of the tube as a mould. For the first time it proved possible to drain the ladle and tundish at will, rather than by good chance, and the annular mould design with flexing gap was adopted as standard, and a fabricating specification was prepared. The width of the flexing gap, initially about $\frac{1}{32}$ in., was later increased to $\frac{1}{16}$ in. to ensure clearance in the routine preparation of moulds.

Initially, the mould tubes were fabricated with $\frac{7}{16}$-in. thick walls and $\frac{1}{2}$ in. corner radii, and used in the fully annealed condition. Later, the adoption of $\frac{1}{4}$ in. corner radii was found to improve the shape of the billet and the quality of its surface. Subsequently, $\frac{1}{4}$-in. tube wall thickness became standard when found to permit casting at higher speeds. The modern design of 2-in. square moulds thus evolved is shown in Fig. 39. Supplied with water at 40–45 lb/in^2 pressure, water velocities of the order of 25 ft/s are obtained up the $\frac{3}{16}$-in. wide annulus around the mould tube. Flow rates average about 140 gal/min and the water temperature rise is about 10° C, giving an overall heat transfer rate of 140 gal.° C/min.

Flexing of the mould tube appears to be a characteristic of its operation when casting speeds are greater than about 165 in./min. This apparently critical level has been confirmed for 3-in. square moulds and appears also true for 2-in. square tubes. Except at low casting speeds (well below 165 in./min), if flexing of the mould tube is prevented, breakouts occur at longitudinal corner cracks. At speeds a little below 165 in./min, although no flexing occurs during casting, the tube seems to operate in a statically flexed condition, but not always to the same side. Above 165 in./min, if casting satisfactorily, the tube is always seen to be flexing, this being shown by the emerging billet. The surface temperature of the latter on any one side or corner continually varies from a relatively bright to a dark appearance, the range being estimated at about 900–1 300° C.

The cause of flexing seems to be associated with the following mechanism. The skin or newly formed wall of the billet shrinks off the mould faces at a level only one or two stroke lengths below the meniscus. It has been proved at Barrow, by transmitting ultrasonic waves across the mould tube, that the billet skin is separated from the mould faces, as might be expected, at each upstroke of mould reciprocation, but it is probable that shrink-off occurs a little later when the skin strength has increased. It is likely that the thickening skin shrinks away from the mould faces but remains supported or in contact with at least one face, or two faces at a corner. At this contact position heat transfer to the mould tube continues as the billet descends and the mould wall is hot and therefore expanded, whilst the billet wall is being cooled and therefore contracts. At the same level on the opposite side no contact exists; the mould tube is cooled, and therefore not expanded, whilst the billet wall tends to heat up and expand. The net effect is that the mould tube is bent thermally towards the billet and the billet wall likewise also towards the tube, thus accentuating the pressure at the position of contact considered. The result is that contact with this position on the billet surface considered is maintained as the billet moves down the mould tube, whilst owing to reaction effects the point of contact at higher levels is moved round the mould tube to the opposite side. The process of the formation of a contact point on one side of the billet is thus continually being repeated against different sectors of the mould perimeter at the initial shrink-off level in the mould, and these descending contact points cause the continual flexing of the mould tube, as well as resulting in the continually varying surface temperature of the emerging billet. The position of contact moves round the mould tube either clockwise or anticlockwise, precessing continually.

Regular flexing action is generally consistent with good casting performance above 165 in./min and up to the maximum speeds obtainable. Thus, a $\frac{7}{16}$-in. thick mould tube was found to flex up to its maximum casting speed of 270 in./min. Just above 270 in./min, say up to 275 in./min, observation of the surface of the billet emerging from the mould shows it to be scintillating and shining brightly like liquid steel. If speed is reduced from 275 in./min, the normal wall-formation process recovers but (as checked several times) just above 275 in./min, no matter what is done, the metal breaks out and the wall collapses entirely before reaching 280 in./min.

Reduction of the 2-in. mould-wall thickness to $\frac{3}{4}$ in., still holding to a $\frac{3}{16}$-in. annular water passage, allowed casting speed to be increased above 280 in./min, and in fact the maximum speed for this type of mould is not known. Speeds of 360 in./min have been obtained with no change in the appearance of the emerging billet, apparently stable flexing action occurring at these speeds also. Incidentally, compared with $\frac{7}{16}$-in. or $\frac{1}{2}$-in. thick mould tubes, $\frac{1}{4}$-in. tubes do not show any appreciable increase in heat transfer. No simple explanation exists for this, nor for the fact that higher casting speeds are possible. The matter does not, however, appear to be mainly a heat transfer problem.

Overall heat transfer to the mould appears to be influenced by a number of other factors. In the main, superheat in the metal supplied to the mould has a direct effect, increased superheat increasing heat transfer on an almost *quid pro quo* basis, whilst for carbon steels, particularly with carbon contents grading below 0·20%C, the heat transfer to the mould is increasingly reduced. The rate for 0·10%C steel is only about 70% of that for 0·30%C steel.

Flexing action gives freedom from any appreciable degree of mechanical wear at the mould faces. With non-flexing mould tubes the bottom of the tube, even though chrome plated, became severely worn. The surface, mainly in the corners, appeared to be rasped out progressively from the bottom of the tube upwards, and the wear progressed the longer the tube was in use. With flexing, no wear of this type occurs whatever, even if the copper tube is not chrome plated. Tubes are preferably chrome plated, first because the chrome-plated surface, which is applied by special techniques, provides a smooth low-friction surface

and, second, because it prevents a long-term form of deterioration which tends to occur with unplated copper moulds. After a number of casts, unplated tubes show one or two small pock marks on their inside faces and further casts result in score marks down the mould tube owing to steel solidifying in these small holes. Meanwhile, other pit holes form and lead to further score marks. One can imagine at the surface of the mould tube small copper crystals existing with shapes similar to a pyramid, the apex of the pyramid or shape pointing inwards If the surrounding crystal structure of the wall is stressed and strained under the thermal conditions of casting, the adjacent crystals can move to accommodate the stresses and, in doing so, would appear to shoulder the pyramid-shaped crystals so that they loosen and eventually are pushed out, or get pulled away. A relatively strong chrome-plated surface, usually only 0·003–0·004 in. thick, prevents loss of these crystals and probably also their loosening. Because of its adherence and thinness, the chrome layer has no effect on heat transfer.

The advantages of mould flexing action can be summarized as follows:

(i) It results in relative freedom from longitudinal corner crack formation
(ii) More controlled and greater heat transfer to the mould wall is given, allowing higher casting speeds
(iii) It reduces damage to mould tubes by eliminating rasping action
(iv) Mould tube straightness becomes less critical, so that commercial preparation of moulds is facilitated.

Mould reciprocation and negative strip

At Barrow the mould is reciprocated vertically, as done by Junghans and others, but with the important difference that negative strip is introduced. As previously indicated, conditions for billet wall solidification within the mould are appreciably improved. Reciprocation with negative strip has been termed the ' Barrow principle.'

A simple 3 : 1 ratio cam is used to move the mould downwards at speeds corresponding to, but slightly faster than, those of billet descent for about three-quarters of each reciprocation cycle. In each remaining quarter cycle, the mould is then raised relatively quickly (about three times the descent speed). The speed of the cam, and therefore of mould reciprocation, is geared to the billet withdrawal speed. Hence, for all casting speeds, the movement of the billet can be superimposed on a diagram of mould movement which, basically, is the profile of the cam. This is done in Fig. 40. The line ABC is the mould movement to a time base-line of one complete reciprocation cycle, as represented by the cam profile. Between A and B, the mould descends through its own stroke length at nearly constant rate for three-quarters of the cycle, whilst between B and C the upstroke occurs. The dotted line JJ represents the superimposed descent of the billet, if conditions are synchronized as is done when operating on the Junghans principle. The lines KK and LL represent likewise the billet descent if slower or faster, respectively, than the mould. Since all these lines coincide at the beginning of mould descent, the differences at the end are real in the case of KK and LL and, as indicated on the diagram, are known as ' negative strip ' and ' positive strip ' respectively.

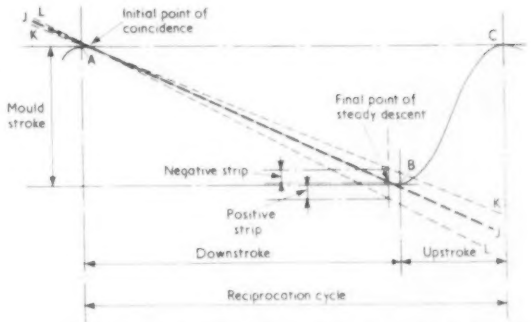

Fig. 40—Diagram showing profile of standard 3 : 1 ratio cam for mould reciprocation with lines of billet descent superimposed to show the Junghans principle of synchronization, the Barrow principle of casting with negative strip, and the undesirable condition which involves positive strip

The preferred relationship is the line KK against the profile ABC, i.e. with the mould descending slightly faster, so providing a suitable amount of negative strip. The arrangement is obtained on the machine simply by correct setting of the gears in the driving shaft to the cam. Mould stroke is chosen usually between $\frac{3}{4}$ in. and $2\frac{1}{16}$ in. to obtain mould frequencies at the expected casting speeds high enough to suit the power available from the main drive motor and not so high as to cause excessive vibrations in the machine structure. Usually, 2-in. billets are cast with a 2 in. stroke at average speeds up to about 300 in./min, and the negative strip arranged for is normally between $\frac{1}{32}$ in. and $\frac{1}{8}$ in. It may need to be increased to as much as $\frac{3}{8}$ in. if mechanical maintenance of pins and joints in the link system is lacking, but usually $\frac{1}{32}$–$\frac{1}{16}$ in. suffices. For 3-in. billet, stroke length is usually about $1\frac{1}{8}$ in. and negative strip about $\frac{1}{32}$–$\frac{1}{16}$ in.

The condition of operation represented by the line LL against the cam profile ABC in which the mould drags behind the billet, so introducing positive stripping action, is to be deprecated. Any attempt to cast at reasonable speeds with this condition results immediately in false-wall formation and a breakout at the bottom of the mould. It is, however, important to recognize the condition because mechanical wear of pins and joints may occur introducing lost-motion and backlash into the mould movement and, in time, the mould hardly travels as far as the billet in its downstrokes. Positive strip then replaces the initially arranged negative strip and a breakout occurs. To compensate, the amount of negative strip tends to be increased if mechanical maintenance is lacking, although in a production plant preventive maintenance in this respect would eliminate the question.

Alternative forms of mould reciprocation have also been tried at Barrow. In Fig. 41, the standard 3 : 1 ratio cam is shown reversed in profile. If the standard cam is reversed on the machine, then in operation it reciprocates with a 1 : 3 ratio. When the

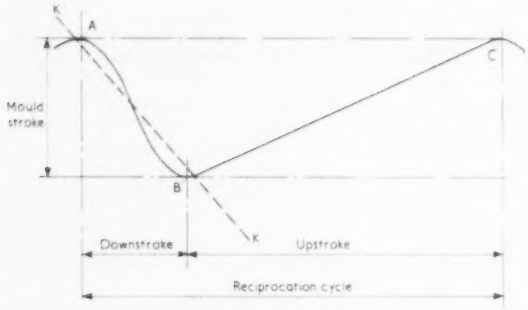

Fig. 41—Diagram showing use of a reversed cam with 1 : 3 ratio developed at Barrow

gearing is correctly adjusted, so that the descent of the billet can be represented by the line KK against the profile ABC in Fig. 41, the mould again descends at an average speed which is slightly faster than the billet, i.e. with negative strip in the first quarter of the cycle. The mould then returns in the remaining three-quarters of a cycle at a relatively slow speed, about one third of its average descent speed. Use of a reversed 1 : 3 ratio cam was first suggested by Mr Rossi as a means of reducing the upward drag of the mould on the newly formed skin of the billet. The method operates very successfully if coupled with the Barrow technique of using negative strip in the downstroke. Typical stroke lengths have varied from 2 in. down to $\frac{5}{16}$ in. with moulds of different sizes, in all cases the negative strip used being about $\frac{1}{4}$ in.

Figure 42 shows the profile of a 1 : 1 ratio cam, also tried at Barrow on various mould sizes and under various conditions. The cam has been used in the forward and reversed arrangement with strokes varying from 2 in. down to $1\frac{3}{16}$ in., again with $\frac{1}{4}$ in. of negative strip.

It is preferred to limit consideration of such alternative forms of mould reciprocation to the above details and reserve for the present further information on this aspect of the work at Barrow. The main advantages of negative strip or reciprocation on the Barrow principle can be summarized as follows:

(i) Its use reduces drag and prevents sticking between the newly cast billet skin and the mould faces, so eliminating false-wall formation and making possible normal high casting speeds
(ii) If sticking occurs, due perhaps to temporary lack of lubricant, it releases the attached billet skin compressively
(iii) During normal high-speed casting it prevents the formation of cracks on the billet surface by compacted crystallization
(iv) If any cracks do form by drag during the upward stroke of the mould, it closes them and produces conditions causing them to weld up
(v) It can be used to combat mechanical wear in the cam-and-link system
(vi) It is also used when employing alternative forms of mould reciprocation.

Mould life

As yet, insufficient casts have been run at Barrow to allow more than a rather incomplete picture on mould life to be presented. One reason is the continuing and varied programme of development.

Annealed 2-in. square mould tubes with $\frac{7}{16}$-in. thick walls were found to cast well at first, but after about 12–14 casts a breakout would suddenly occur at a longitudinal corner crack. This kind of fracture would occur without the formation on the billet of any surface undulation with its localized higher temperature. Nevertheless, there was warning of mould failure. Mould water temperature rise for a new annealed tube would be about 12° C, but with each ensuing cast this rise was noticed to decrease progressively. The temperature rise towards the tenth cast would average about 8° C and an average rise of about 6·8° C obtained when the breakout occurred or was imminent. Any attempt to use the mould again after the occurrence of the breakout merely resulted in another breakout.

At this stage, initially regarded as the completion of life, the tube itself appeared indistinguishable from a new tube. No difference at all could be detected, except by a hardness test performed with a Rockwell hardness testing machine, but using a modified technique. By this test a fully annealed as-new pure copper tube gave an indentation reading of 70 arbitrary scale-units, whilst a thoroughly hard as-drawn tube gave a reading of 44 units, the full range of hardness thus being from 70 to 44, soft to hard.

Check tests made every few casts on several mould tubes during their life, testing at points along their length on the outside of each face, showed that each annealed tube progressively hardened to a small extent at its lower end, but to an increasingly greater extent up the tube to the hottest zone of operation, a few inches below the flange. At the end of its life, when the breakout had occurred, the average reading at the lower end was about 66, and at the hot zone about 56. Some form of progressive work-hardening had apparently taken place during service, possibly associated with the continued flexing action of the tube when casting. A survey by the British Non-Ferrous Research Association of a used tube, cut into sectional rings, confirmed these findings for its outer surface but could not establish any corresponding changes within the walls at any position. Thus, such work-hardening as had perhaps occurred appeared to be confined to surface changes.

A method of 'resurrecting' the used mould tubes was devised by annealing them at 600° C. After this treatment tubes were found to be capable of

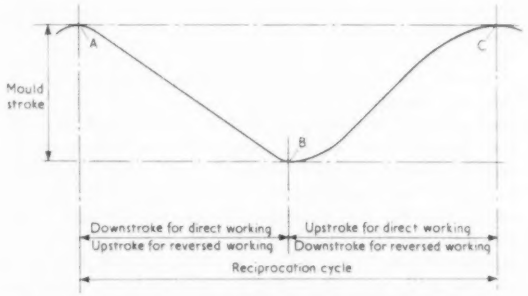

Fig. 42—Profile of 1 : 1 ratio cam as used at Barrow in the direct and reverse directions

casting for a further term which followed much the same pattern as the first life except that deterioration was somewhat more rapid. Further annealing allowed a third and even a fourth life, but the latter, in the few cases tried, only appeared to amount to a few casts.

In view of the progressive hardening of annealed tubes it was at first thought that hard tubes in the as-drawn condition might not be suitable for use. This was, however, disproved when two $3\frac{5}{8}$-in. square moulds were used successively, one annealed and one as-drawn, to the end of their first lives. The initially annealed tube had a life of 25 casts and the initially hard tube 22 casts. Hardness checks on the annealed tube showed it to have hardened progressively to approximately the same distribution as observed with the 2-in. tube, whilst the initially hard tube had softened progressively to a similar distribution of hardness along its length as finally found on the initially soft tube. The hard tube had thus apparently annealed progressively, yet not completely nor to a similar degree along its length. Similar results observed with other moulds yielded no new information, except that in a second life change of surface hardness followed the pattern observed for first life.

The question of mould tube life was greatly altered with the introduction of thin-walled ($\frac{1}{4}$-in. thick) tubes, which do not appear to change their character in service. Thus, repeated trials with thin-walled 2-in. moulds has indicated no progressive decrease in the temperature rise of the cooling water, nor any apparent deterioration in the ability of the tube to flex during casting, a feature frequently observed towards the end of life with $\frac{7}{16}$-in. thick tubes. More important, the $\frac{1}{4}$-in. wall tubes continue to operate in a relatively stable manner, cast after cast, with no sign of wear or other deterioration. Insufficient casts have been run to determine any limit of life for 2-in. square thin-wall moulds, but the evidence is fairly strong that the life must be quite considerable. Thus, data for incomplete lives on at least three tubes exist:

Mould no.	*No. of casts made to date*	*Tonnage produced to date*	
61	37	234	Single-strand casts
66	42	126	Twin-strand casts
67	44	131	Twin-strand casts

These moulds are still capable of continuing to cast as new and the position is perhaps best put into focus by indicating that for a tube similar to no. 61 the cost would probably be about 2*s*. 6*d*. per ton of steel produced, and this cost will decrease as its production is continued.

Mould life data on 3-in. square and 6-in. × 2-in. slab mould tubes is not really known, partly because of insufficient runs to build up data, but mainly, because of the considerable variability in the performances of the tubes tried. Thus 3-in. square moulds have given first lives varying from 6 to 18 casts, and have shown no set pattern of variation, either in mould temperature rise or in flexing ability. The general position appears to be similar to that existing for 2-in. moulds before the introduction of the thin-wall design. Various 3-in. square tubes with wall thicknesses varying from $\frac{1}{4}$ to $\frac{1}{2}$ in. have been tried,

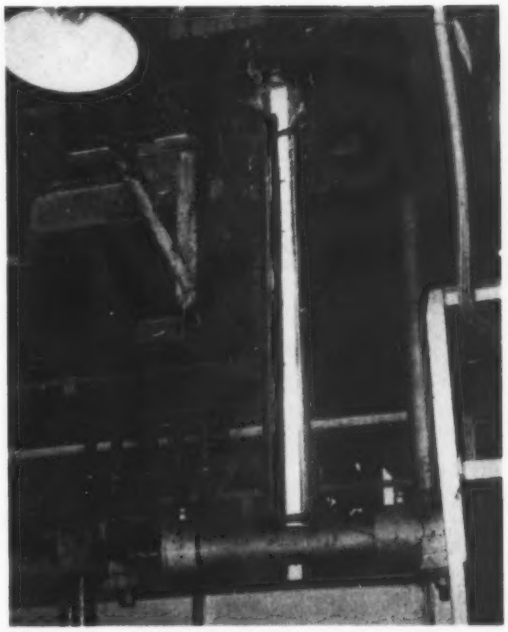

Fig. 43—Early spray arrangement of four face-centred pipes suspended so as to swing with the descending billet on the single-strand machine

but as yet, no consistent differences in performance have been discernible against the background of general variability. However, there would appear to be no reason why mould life data for 3-in. square and 6-in. × 2-in. slab tubes should not be comparable with that for 2-in. square moulds. The position may well be more favourable in terms of cost because of the relatively larger tonnages able to be cast in these larger sections.

One feature of interest bound in with the experience on 3-in. square and 6-in. × 2-in. slab moulds is the effect of metal quality cast on mould life. The performance of these moulds is appreciably more precarious for 0·10%C steels than for 0·30%C qualities, and for the latter than for 0·60%C steels.

SPRAY COOLING

Whilst the mould performs the primary function of solidifying the wall of the section being cast, the directly applied water sprays below the mould complete solidification. This solidification requires to be promoted by heat removal through walls which thicken as the billet descends. The character of the sprays and the resultant pattern of heat removal determine the mode of solidification of the liquid centre and, in this way, have a direct bearing on the structure of the product cast.

General aspects of spray cooling

A basic consideration in spray cooling to solidify the inner crater of liquid metal in a billet or section withdrawn from a mould is the relationship of crater depth to section size and casting speed. A relatively simple equation which may be used tentatively to

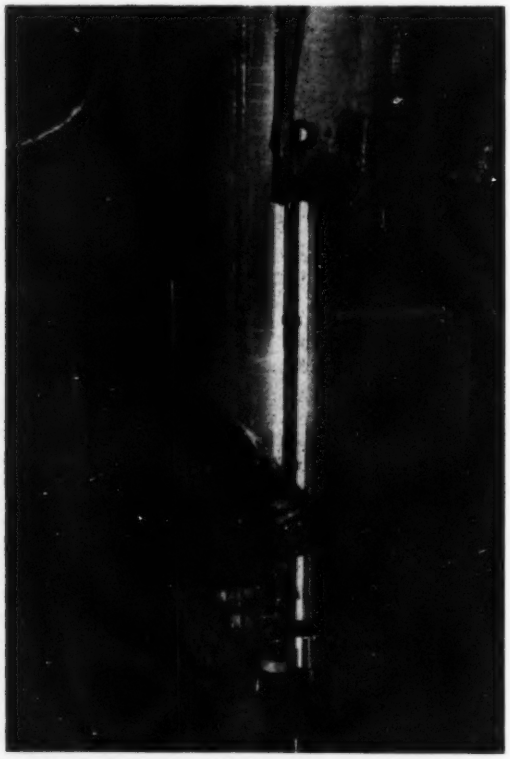

Fig. 44—Close-up of jet sprays arranged to spray in zones with reheat intervals as tried on single-strand machine

obtain an indication of crater depth in billets takes the form:

$$Z = KVd + C$$

where Z = crater depth, (in.), usually measured from the bottom of the mould; V = casting speed, (in./min); d = dimension (side) of section, (in.); K = a constant function, (min/in.), which includes an average surface heat-transfer coefficient to the spray water and by radiation to surroundings, and may show a small dependence on the section size, i.e. dimension d, and also on casting speed V; C = a constant (in.), which is small numerically in value and is usually neglected if Z is measured from the bottom of the mould. The formula gives an approximation and for the spraying of small sections as at Barrow, the value of K lies between 0·10 and 0·12 min/in. Thus, at Barrow, the equation is sometimes used in the form:

$$Z = 0{\cdot}1\,Vd$$

the units being as indicated above.

The formula indicates that for higher casting speeds or larger dimensions the minimum length of the spray cooling zone required will increase unless the strength of the sprays themselves is intensified. If the minimum length becomes greater than the available length of sprays, solidification will be incomplete. The billet centre is then likely to be still liquid at cut-off because, below the sprays, heat loss by radiation at slow rates only remains and the time interval is short before the cut-off station is reached. To some extent, therefore, the maximum speeds of casting on any given machine are limited by the length of spray units available for each size and, in this respect, the high casting speeds normally obtained at Barrow for the 8 ft 6 in. length of spray zone used indicate fairly good efficiency in heat removal.

The water sprays should be applied to the billet as evenly as possible round its perimeter at all levels. Reference has already been made to the reactions of the descending billet if rigidly mounted and carefully centred spray units are employed, and to the use of swinging sprays to prevent it from bowing laterally and snaking down through the spray zone. Apart from suspension, various methods of applying the water have been tested. Thus, vertical pipes opposite the billet faces were tried with various arrangements of drilled holes, e.g. one or more vertical lines to jet directly at the face centres, and/or across to the corners. Alternatively, various transversely cut slots of different width at differently spaced intervals were adopted. Various types of nozzle have been mounted on the pipes and, in some cases, pipes were positioned to spray more directly at the billet corners than at its faces. Figure 43 shows an early system of four face-centred pipes suspended to swing with the billet. One modification, in which spraying was applied in zones with intervals between to allow the billet to reheat from the inside, and thus allow some annealing action at the directly cooled surfaces, is shown in Fig. 44. These and other sprays were also tried suspended to the bottom of the mould so as to be reciprocated vertically with mould movement. None of these arrangements, however, resulted in a cast structure appreciably better than the others. Internal cracks and central porosity in the structure occurred in all these cases to a marked degree and it was not until the hollow cone sprays were adopted and used as already described that an appreciable improvement in product quality was obtained.

In general, it seems desirable to deliver the billet to the withdrawal rolls at as hot a temperature as possible, consistent with complete solidification. The average intensity of the sprays can be varied easily by control of the water supply to the spray units, and this is done in semi-production runs to produce good quality. Reduction of overall spray intensity is occasionally necessary to aid the bending and straightening of sections for horizontal discharge.

Use of hollow cone sprays

It seems worthwhile considering some of the basic aspects of the use of hollow cone sprays since their application has been found, at Barrow, to result in sound internal structures for several product sizes cast at various different speeds.

Figure 45 shows diagrammatically the structure of a single hollow cone spray with a rating of 20 gal/h, as used for spraying 2-in. square billets. Each nozzle is set back from the billet face a distance of 2 in., and the hollow cone spray is arranged to strike the billet with an 'impact ring' having an outside diameter of about 2 in., or approximately equal to

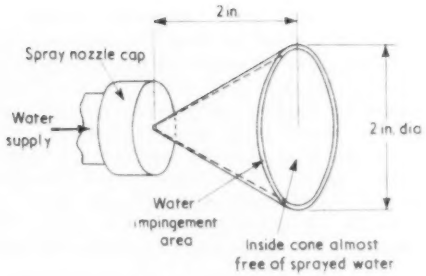

Fig. 45—Sketch of hollow-cone spray unit used for continuously casting 2-in. square billets

the width of the billet face. The film thickness of the cone is about $\frac{1}{16}$ in. on approaching the billet surface and the width of ring affected by the impingement of the spray water and its rebound is perhaps double the film thickness, i.e. about $\frac{1}{8}$ in.

To consider the cooling action of the spray cone from the point of view of the billet descending through it, it is necessary to integrate the vertical path of various points across the billet surface as they descend through the annular ring affected by impingement and rebound. An annulus, or cone, with outside diameter 2 in. and thickness $\frac{1}{8}$ in., may be classified as having a hollow ratio of 0·875, as distinct from a similar ring of $\frac{1}{4}$ in. thickness with a ratio of 0·75. The integrated paths are equivalent to the instantaneous ratios of vertical height affected by spray impingement to unit length of billet and therefore give a distribution of the overall intensity of these cone sprays across the face of the billet. In Fig. 46, the integrated intensities are plotted against distance from the centre-line of the billet face, scaled as ratios to the half-breadth, and are seen to have a characteristic distribution which is relatively independent of the face width, and is only affected by the magnitude of the hollow ratio of the spray cone.

It was intriguing to find that hollow-cone sprays had such a pronounced effect on the conditions of solidification and in producing sound internal structures. It seemed that the characteristic distribution of spray intensity plotted in Fig. 46 might well have some specific influence on the mechanism of solidification.

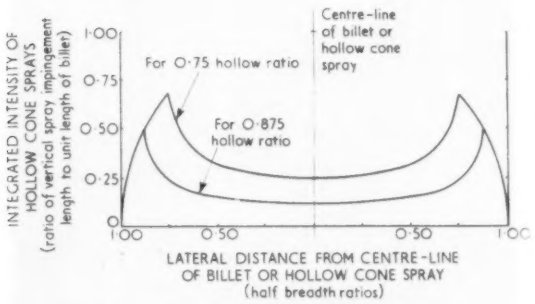

Fig. 46—Integrated intensity of hollow cone sprays across the face of the sprayed billet (from the impingement area of a given size of hollow cone spray)

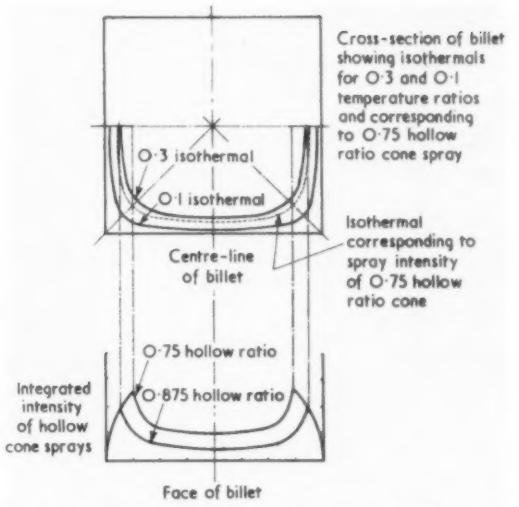
Cross-section of billet showing isothermals for 0·3 and 0·1 temperature ratios and corresponding to 0·75 hollow ratio cone spray
0·3 isothermal
0·1 isothermal
Isothermal corresponding to spray intensity of 0·75 hollow ratio cone
Centre-line of billet
0·75 hollow ratio
0·875 hollow ratio
Integrated intensity of hollow cone sprays
Face of billet

Fig. 47—Correlation of the integrated intensity of hollow cone sprays across billet faces and isothermals within the billet during spraying

cation. One theory, which may well have a bearing on the position, is roughly illustrated in Fig. 47. The intensity distribution for hollow cone sprays, having hollow ratios of 0·875 and 0·75, are compared with the well known isothermal temperature distribution lines for the cooling of a square section from an initially even temperature by a constant cooling flux at its surfaces. The conditions are not exactly comparable to those for a continuous cast billet solidifying and liberating latent heat as it descends through the sprays. Nevertheless, if conditions at a typical level within the spray zone are considered, and if the above type of isothermal cooling for the solidified portion is, for the moment, assumed to be desirable, then it would be necessary for the sprays to produce within the cast wall of the section at least one temperature contour of the series which includes the isothermal lines shown in Fig. 47. Such a temperature contour might well be close to the inner isothermal of Fig. 47 corresponding, say, to a temperature ratio of 0·3. The normal distance of such an isothermal from the face of the section varies in a characteristic manner across the face, being least at the centre-line of the section and greatest at the intersection of the isothermal line with the diagonals to each corner. It may then be noted that a cone spray of hollow ratio, say 0·75, produces a distribution of spray intensity which, in curvature, is similar but more accentuated than its corresponding isothermal, i.e. that within the square section, marked off on the diagonals by projections from the peak values of the spray intensity distribution, and shown by the dotted isothermal seen in Fig. 47. The more accentuated curvature for spray intensity would appear necessary to absorb the greater amounts of heat liberated near the corners or diagonals of the section, since solidification is in progress and has to advance by thicker layers near the diagonals than on the centre-line of each quadrant. If, within the solidified portion of

Fig. 48—View of early single-strand casting machine operating with mechanized cut-off torch and tippler plate discharge

the billet, one contour of temperature similar to those shown in Fig. 47 could in this way be established, it then seems reasonable to expect that the subsequent contours of solidification would maintain a similar isothermal pattern.

Hence, as solidification progressed, the temperature distribution in the solidified portion of the billet would tend to approximate to that known for uniform cooling conditions without solidification. If, then, the postulated contour of cooling could be maintained until solidification is complete, the resulting temperature pattern in the solid billet would be close to that assumed desirable in the first place and known to result in a solid section of the same size from very uniform conditions of heat removal. Under these conditions the stresses within the solidified portion of the section would seem to be minimized at all stages until complete solidification is obtained. Therein, perhaps, lies the efficacy of hollow cone sprays.

The impact ring diameter of the cone sprays is increased for larger billets, as also is the amount of water applied per spray nozzle, namely 20- and 30-gal/h nozzles are used for 2- and 3-in. square billets respectively. In the case of 6-in. × 2-in. slabs, the solidification problem is less severe, but is still one associated with freezing at, and within, four corners; therefore, the broad faces are sprayed at their edges at least with nozzles similar to those used for the narrow faces, e.g. by 20-gal/h nozzles as for the 2-in. faces, there being three pipes carrying these nozzles opposite the broad face. Likewise, a 9-in. × 3-in. slab might be sprayed by 30-gal/h nozzles as for 3-in. square billet. The intensity of the sprays from top to bottom of the 8 ft 6 in. cooling zone is normally maintained as uniform as possible and their overall strength is varied with casting speed to produce good quality, the nominal maximum water flows to the spray system for 2-in. and 3-in. billets being 64 and 85 gal/min respectively and, for 6-in. × 2-in. slab, 75–128 gal/min depending on speed. Actual water flows to the spray units are somewhat less.

CUT-OFF AND DISCHARGE DEVICES

Whilst the present standard procedure at Barrow of bending the cast sections to horizontal delivery along roller tracks has already been described, it is worth noting briefly the earlier method whereby the descending billet was flame-cut by a mechanized torch, as shown in Fig. 48, and the cut lengths were thereafter discharged to a collecting pit. A similar or improved torch operation could, of course, be applied to horizontally discharging billets, whilst, if a steel quality were found that did not lend itself to bending this method of delivery could be adopted.

An oxy–propane torch was mounted on a traversing mechanism near ground level so as to cut the billet during its descent. The mechanism was supported on a frame fitted with an air-operated clamp, between the faces of which first the dummy bar and then the hot billet were made to descend. On starting to cast, the dummy bar emerged through the clamp and its lengths were disconnected, in turn, at the pinned joints. When the hot end of the billet emerged beside the cut-off torch, air pressure was turned on to clamp the frame to the descending billet and to

Fig. 49—Close-up of mechanized torch cutting 2-in. square billet during operation of single-strand machine

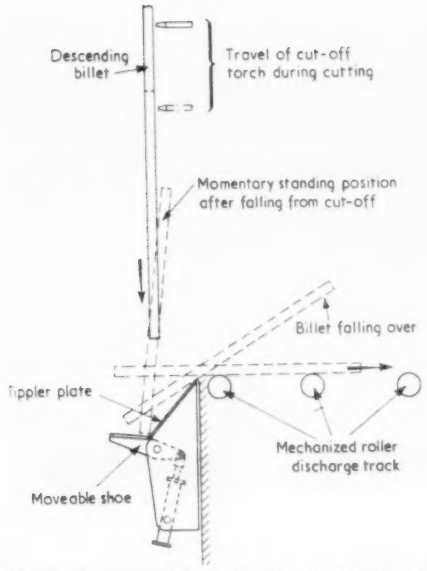

Fig. 50—Operating principle of discharge tippler plate developed for continuously cast billet discharge

energize, at the same time, the torch traversing drive. The frame also descended with the billet, whilst the torch traversed horizontally. Iron powder was injected into the flame to aid cutting and, although not essential for carbon steels, gave greater reliability. The use of iron powder at the cut-off torch was, of course, indispensable when casting high-alloy qualities such as 18–8 stainless steel.

The torch thus descended with the billet as it cut across the section. Figure 49 shows a close-up view

Fig. 51—Billet length cut to 6 ft by mechanized torch, falling towards the discharge tippler plate on single-strand machine

Fig. 52—Billet length delivering into the collecting pit from the angled guide plate on the discharge roller track of the single-strand machine

of the torch during this operation. The withdrawal rolls started each cut by triggering magnetic valves to pass air to close the clamp and, at the same time, start the traversing motor. The torch halted itself automatically at the end of each traverse and reset the magnetic valves, thereby opening the clamp. The frame, thus released, then returned to its upper position ready for the next cut. The cut length, usually 6 ft, could be varied by re-setting a gearbox and lengths varying from 6 ft to 10 ft could be cut if desired.

Each cut-off billet length dropped so that its lower end struck a sloping tippler plate and came to rest on a shoe at the bottom of the sloping plate. The principle of operation of the discharged tippler plate is shown in Fig. 50. Each length stood momentarily at a slight angle, leaning towards the tippler plate, and then fell against the plate and over its top edge on to a mechanized roller track. No moving parts were involved in the operation of the tippler plate. Its length, however, required to be shorter than half the cut billet length and, for this reason, the plate itself could be mounted at different heights so as to vary the distance from the shoe to the top edge over which the billet fell. The shoe itself was supported on a fulcrum and powered by an air cylinder so that, if desired, it could be made to flap downwards in emergencies, e.g. if the cut-off torch failed to cut the billet. Each billet was removed in turn by the roller track, set just below ground level, and guided in transit by an angled plate was deposited under its own momentum into a collecting pit. Figure 51 shows a billet length falling towards the tippler plate below ground level, whilst Fig. 52 shows a 6-ft billet discharging into the collecting pit.

PRODUCT STRUCTURE AND QUALITY

No-one should be in any doubt that the billet and slab sections produced on the casting machine at Barrow are cast sections and not rolled material. The products have a cast structure and require to be rolled, forged, or hot-worked to some degree before being used for engineering or other purposes.

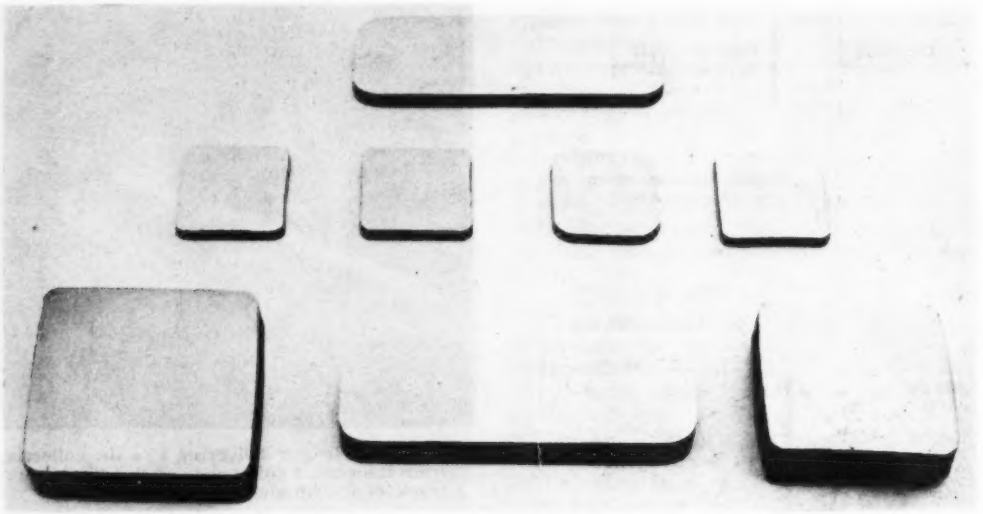

Fig. 53—Typical assortment of 2-in., 3-in., and 3⅝-in. square billets and 6-in. × 2-in. slab sections cast in various carbon and stainless-steel qualities

Thus, Fig. 53 shows a number of cast sections, namely mild-steel 2-in. square billet with ½-in. and ¼-in. radius corners, high-carbon 2-in. square billet and stainless steel 2-in. square billet, medium-carbon 3-in. square and low-carbon 3⅝-in. square billets, and also high-carbon 6-in. × 2-in. and stainless-steel 6-in. × 2-in. slabs. In Fig. 54 are some of the products to which these sections have been rolled, and which may be distinguished as: Y-bar section, 1-in × 20-gauge hoop strip, weldless steel tube from 3⅝-in. billet, 1½-in. sharp-corner square-rolled bar, medium-carbon 1½-in. × ¼-in. square-cornered flat bar and silico-manganese 1½-in. × ⅜-in. round-corner laminated spring-steel bars, 1¼-in. and 2-in. dia. black rolled and 2-in. dia. bright rolled round bars, and a piece of stainless steel sheet rolled from 6-in. × 2-in. slab.

The quality of the product cast at Barrow is good. It is proposed to illustrate the normal features of the product and also mention features of malformation and poor quality. It should, however, be noted that

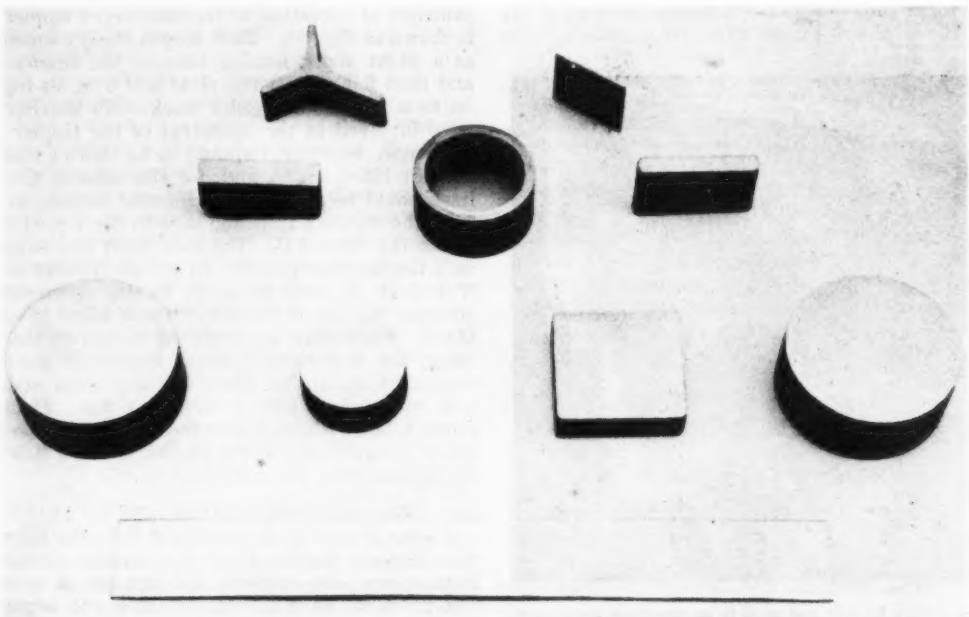

Fig. 54—Assortment of products rolled from billet and slab sections

Fig. 55—Surface appearance of 2-in. square 0·35%C steel billet

the reproduction of metallographic-section photographs of cast material is not easy because the specimens become rapidly stained during photography around positions where central porosity or small internal fissures occur. As a result the impression given by the photographs is that the nature of these features is much more severe than would be seen by direct examination of the etched specimens.

Surface character and quality

The billets and slabs are generally regular in shape and have a good smooth surface on which, however, can be seen light ripple marks corresponding to the reciprocations of the mould. These marks are often only a difference in surface texture, as is indicated by the 0·35%C billet in Fig. 55. The quality of the metal cast has some effect on the severity of the ripple mark, metals with a high shrinkage on freezing tending to show more severe ripple formation. Thus, the high-nitrogen valve-steel billet in Fig. 56 has a more pronounced ripple formation, though still of good quality. Also, low-carbon steel, particularly below 0·10%C, because of its softness tends to show a heavier ripple-mark formation.

The ripple mark is not formed as an overlap but is rather an undulation of greater or less severity formed during the solidification process of the skin or wall of the billet. Something of its nature can be observed in Fig. 57, which is a close-up of the ripple marks on the high-nitrogen valve-steel billet shown in Fig. 56. These ripple marks disappear entirely in the early stages of rolling and present no problem to the processing of the material. In many cases, continuously cast billet is preferred at the re-rolling mills because of its regularity of shape and structure, and for its freedom from overlaps and other defects found in orthodox billets rolled in intermediate mills from cast ingots. In addition, the amount of dressing required by cast billets before re-rolling is very considerably less than normally necessary with orthodox billets.

On the malformation side the ripple marks may sometimes be found to be heavy or excessive. An example is shown in Fig. 58 by the surface of some 0·30%C billet, the formation of these heavy ripple marks being entirely due to an excessive amount of looseness and backlash in the reciprocating cam-and-link system, and can be eliminated by preventive maintenance. Occasionally, when the operation of the mould is affected by improper lubrication, or certain other faults, the emerging billet shows a type of ' shell ' or ' feather ' formation on its surface. This is local in character, as illustrated on the upper surface of the specimen in Fig. 59, although the formation of the ripple mark is often also disturbed under these conditions. The occurrence of this feature is, however, relatively infrequent.

A somewhat more disturbing defect occasionally occurs, namely, the formation of transverse corner cracks which can sometimes be seen on the billet as it emerges from the mould, but are best observed on a cold specimen after pickling. These cracks are not characteristic of the normal operation of the mould and appear to occur somewhat spasmodically. An example of their occurrence is shown by the 2-in. square 0·35%C billet in Fig. 60. The cracks form close to or at the ripple marks, and the cause of their formation is not as yet fully understood. Rather than be misleading, it seems preferable to let this point rest by noting that the defect occurs only occasionally, that when it does it is usually much less severe than seen in Fig. 60, and that means can be found for its complete elimination in practice. It should perhaps be emphasized that rejections of continuously cast product, before or after processing at the re-rolling mills, have been found in practice to be negligible.

Internal structure

Whilst billet and slab cross-sections show essentially the expected cast structure, little or no segregation is to be found. Sulphur prints taken from the cross-sections are generally nearly as good as those for equivalent rolled sections. The billets generally show a regular square shape although certain 3-in. square mould tubes have shown a tendency to produce rhombic sections. The formation of these rhomboid shapes can be eliminated by the use of

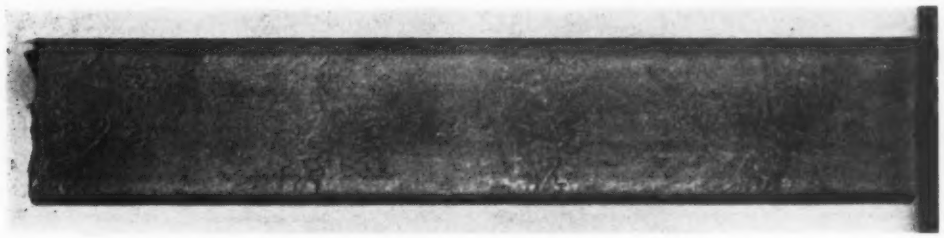

Fig. 56—Surface appearance of 2-in. square high-nitrogen valve-steel billet

Fig. 57—Close-up of ripple marks on high-nitrogen valve-steel billet

tubes made to a close specification. The shape of the 6-in. × 2-in. slab sections is not, as yet, perfect, though still quite useable. Slab shape is dependent upon maintaining a balance between the intensity of spray cooling and casting speed for given qualities. At Barrow these slabs and billets are cast without resort to roller aprons to maintain shape. Incidentally, if withdrawal roll pressure is too large, or if insufficient cooling is applied, billet sections may be deformed, or simply flattened, between the withdrawal rolls. This, however, can be prevented largely by maintaining just sufficient roll pressure to prevent slipping at the roll faces and by sufficient spray cooling.

The sulphur prints show up the slight tendency to central porosity, which can also be observed in etched sections. A typical amount of central porosity is shown in a longitudinal section of 2-in. square silico-manganese billet in Fig. 61 which, due to staining in photography, gives an impression of greater porosity than in fact normally occurs. Minimum porosity is obtained by employing a suitable intensity of sprays below the mould, according to casting speed. If spraying is overdone, or uneven, central porosity tends to be more severe. Rather heavy central porosity is shown in Fig. 62, in a section of 2-in. square 0·65%C billet. If the balance of spray intensity against casting speed for a given quality is not correct, the billet produced sometimes also shows small fissures, or cracks, at positions about half way between its centre-line and the surface. An example of these cracks is shown in a longitudinal section of 0·40%C 2-in. square billet, seen in Fig. 63, again much more accentuated than they are to direct observation. Their occurrence can be eliminated by correct adjustment of sprays. In certain cases, however, this has proved difficult and strong suspicions exist that these fissures partly result from the effects of gas liberation from the metal on freezing. Gas liberation may sometimes also be the cause of central porosity. The occurrence, however, of these cracks is not general and, even when they are present, they do not affect the rolling of the section since they completely weld up in the rolling process, as does also any central porosity which may exist. The two small surface fissures which may be seen on one side of the specimen in Fig. 63 would be much more troublesome in rolling. These two cracks are associated with the conditions producing transverse corner cracks, already discussed.

Fig. 58—Specimen of 2-in. square 0·30%C billet showing heavy ripple mark formation

Fig. 59—Specimen of 2-in. square 0·40%C billet showing shell or feather formation at the surface

Fig. 60—Specimen of 2-in. square 0·35%C billet showing transverse corner cracks at ripple marks

Generally, the walls of the section formed in the mould comprise a very thin outer layer of sub-microscopic or very fine crystals with columnar crystals forming the main thickness of the walls and showing partition lines radiating inwards from the corners between the columnar crystals. This structure can be seen in Fig. 64, which shows a typical cross-section through 0·35%C 2-in. square billet. The columnar zone for this quality is seen to be almost ½ in. thick. The centre of the billet consists of equi-axed crystals solidified mainly in the spray zone. With the lower-carbon steels the columnar crystal formation is generally found to form to a greater depth, whilst with the high-carbon steels the formation of equi-axed crystals is much more marked. Thus, in Fig. 65, showing a typical cross-section of 2-in square 0·65%C steel, the equiaxed crystal formation is spread over nearly the whole cross-section. Columnar crystals do exist near the face of the billet, but are of a finer texture and smaller and do not therefore show to the same degree. The equiaxed crystals for the higher carbon steels also tend to have finer grain sizes, as indicated in Fig. 65.

The higher carbon steels are usually found to contain little or no central porosity, although the section in Fig. 65 does contain at its centre a small pore, somewhat less than pinhead size. The photographic stain may be disregarded. Incidentally, close to the surface of the section in Fig. 64 are shown two subcutaneous blowholes. These blowholes occur if too much lubricant is supplied to the mould during casting or if its flow is not properly distributed. The sample for Fig. 64 was intentionally chosen with blowholes to illustrate the feature, and their formation can be eliminated by correcting the rapeseed oil supply.

Figure 66 shows the typical structure of 2-in. square silico–manganese billet which is rather like that of high-carbon steel, as might be expected since this steel contains 0·53–0·58%C. Other examples of possible interest are illustrated from cross-sections of 3-in. square cast billet. Figure 67 shows the etched section of En 16 quality manganese–molybdenum free-cutting steel. This material has a sulphur content increased to 0·25% to meet customer requirements and its structure consists of fairly massive columnar crystals merging into a central zone of equiaxed crystal formation. Minor central porosity is present. In Fig. 68 is shown the fine structure of free-cutting En 15 quality steel, which also contains 0·25%S. The zone of equiaxed crystal formation

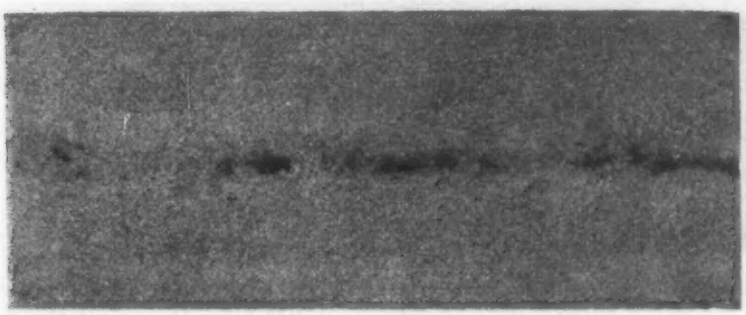

Fig. 61—Longitudinal section through 2-in. square silico-manganese billet (unfortunately stained in photography) showing typical amounts of central porosity

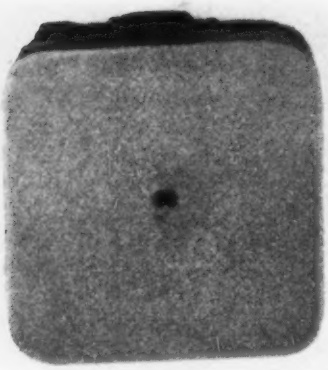

Fig. 62—Section of 2-in. square 0·65%C billet showing fairly heavy centre porosity

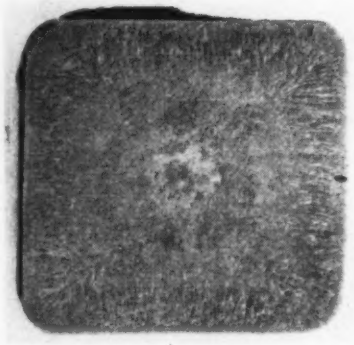

Fig. 64—Typical cross-section through 2-in. square 0·35%C billet

is not only considerably greater, but these crystals are much finer grained, as also are the columnar crystals. The only real difference in analysis between these two specimens is the presence of about 0·30%Mo in the En 16 quality.

As with pure metals, austenitic steels solidify with an inner structure consisting of the continued growth of the columnar crystals to the centre of the section. In a square cast billet the columnar crystals show the diagonal partition lines and meet at the centre. For a slab section the partition lines radiate inwards from the two corners at either end and, between the two points of junction of these lines, a central partition line forms along the broad axis of the slab. The structure of columnar crystals is typical of 18–8 Cr–Ni stainless steel 6-in. × 2-in. cast slab seen in Fig. 69. Along the broad central partition line a thin layer of equiaxed crystals sometimes forms and, generally, the juncture of the columnar crystals appears free from central porosity. A small amount of porosity does, however, exist, but this is spread across the central partition plane, as seen in Fig. 70, which shows a longitudinal section on the partition plane of a 6-in. × 2-in. stainless slab. The change in texture shown by this section is not due to segregation, but rather connected with the fact that the plane of the section cuts along the columnar crystals at the edges of the section, and at right-angles to the end of these crystals in the centre zone, whilst between these zones the crystals are meeting at an angle. The internal structure of 6-in. × 2-in. carbon-steel slabs varies basically in the same manner as do the billets. Low-carbon steels show a columnar formation similar to that of the austenitic steel, but with the formation of appreciable amounts of equiaxed crystals at the centre, whilst medium- and higher-carbon steels show progressively larger zones of equiaxed crystals and greater grain refinement. Thus, as seen in Fig. 71, the section of an 0·55%C 6-in. × 2-in. slab consists of a relatively fine grain structure with columnar crystals at the wall which are hardly discernible from the equiaxed crystals at the centre. There has been no evidence of any deleterious effect on quality due to the procedure of bending the descending sections for horizontal discharge.

The use of an aluminium wire feeder has been developed to control grain size or deoxidize mould metal when casting special steels, but this need not be dwelt upon here.

Mechanical properties

On rolling, the columnar crystal structure is rapidly broken down and the slight central porosity is completely welded up, so that the cast structure disappears. Generally, rolling reduction ratios between 4 : 1 and 8 : 1 suffice to eliminate the as-cast structure.

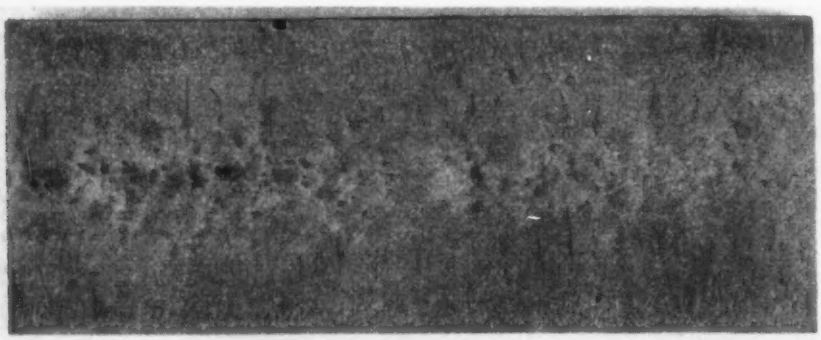

Fig. 63—Longitudinal section along 2-in. square 0·40%C billet showing crack formation halfway between centre and surface owing to incorrect adjustment of sprays

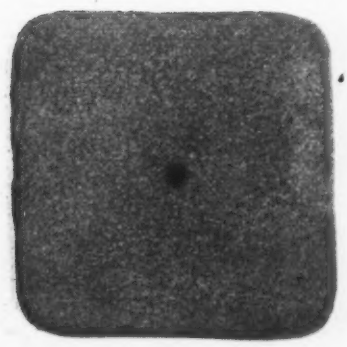

Fig. 65—Typical cross-section through 2-in. square 0·65%C billet

but the ratio depends on metal quality and the condition of the metal at pouring. In individual cases the minimum permissible reduction ratio should be determined by trials. However, the fact that smaller rolling ratios than usual can be adopted may be useful in certain engineering fields where better transverse properties are worth seeking.

As has been mentioned, the cast billets require little dressing and are preferred at the re-rolling mills because of regularity in shape and structure and because of their freedom from overlaps and other flaws which tend to occur in intermediate rolled billets derived from ingots. Continuous cast material is also found to have extremely good forging properties. Hot upset tests, made on 2-in. lengths cut from as-cast 2-in. or 3-in. square billets provide strong evidence of this fact. A 2-in. cube of billet, after being reheated, is forged under a steam hammer with one or two blows struck along the axis of casting so as to reduce the height of the specimen to 1 in. or less. Figure 72 shows a specimen before testing and its typical condition after upsetting. The specimens are usually stamp-numbered before test and during upsetting no tears whatever are found around the stamped contours of the number. Indeed very few of the many upset tests done have shown any noticeable degree of surface crack formation or tearing under this forging operation.

Fig. 66—Typical cross-section through 2-in. square silico-manganese billet

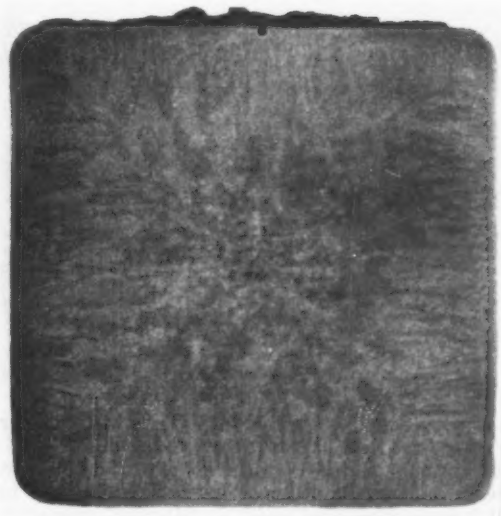

Fig. 67—Cross-section of 3-in. square high-sulphur (0·25%) En 16 quality billet (Mn–Mo)

The physical properties of the products rolled and forged from the cast billets and slabs produced at Barrow have been found to be entirely satisfactory and, in general, not distinguishable in any way from those of good-quality products derived from orthodox ingots.

ECONOMY

Consideration of the various economic aspects and methods of applying continuous casting as a production process is not intended in this paper. These, of course, have been given much attention at

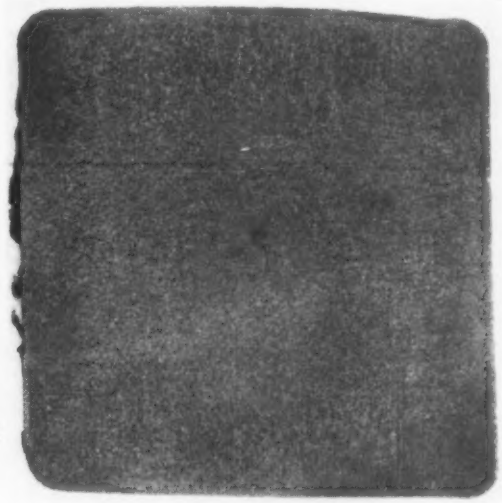

Fig. 68—Cross-section of 3-in. square high-sulphur En 15 quality billet (0·35–0·45%C, 1½%Mn, 0·25%S)

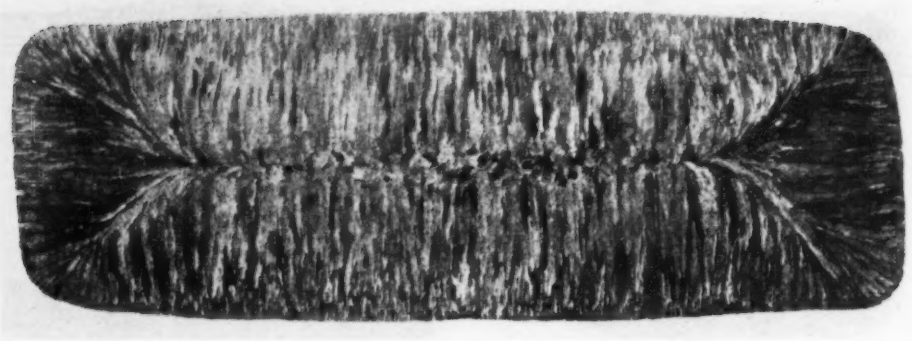

Fig. 69—Typical cross-section of 18–8 Cr–Ni stainless-steel 6-in. × 2-in. slab

Barrow, as called for by the third Term of Reference for the work. It seems appropriate, however, to list the main features which commend the Barrow process as a production method, not only locally to suit Barrow Steel Works Ltd., but also for application elsewhere. The main points of importance are:

(1) The capital cost of a casting machine and associated equipment is relatively low.

(2) The conversion cost per ton of product at the machine can be made competitive for small-section mild-steel billets, which by orthodox means are difficult to produce economically except in large tonnages.

(3) The casting of small-section billets and slabs allows the elimination of appreciable amounts of cogging and intermediate rolling-mill operations.

(4) The Barrow process can maintain high levels of yield, of the order of 98%; also, product quality is good so that dressing operations, scrap recycling, and fuel consumption are all generally reduced.

(5) Manning and maintenance requirements are relatively low and the training of operatives not difficult, if put on the correct foundation.

(6) The process is capable of casting most killed qualities of metal (rimming steel not yet having been seriously attempted), and is suitable for the production of steel qualities which are difficult to cog down in orthodox ingot practice.

These six points have, in the Barrow view, been established and may be quoted in response to the

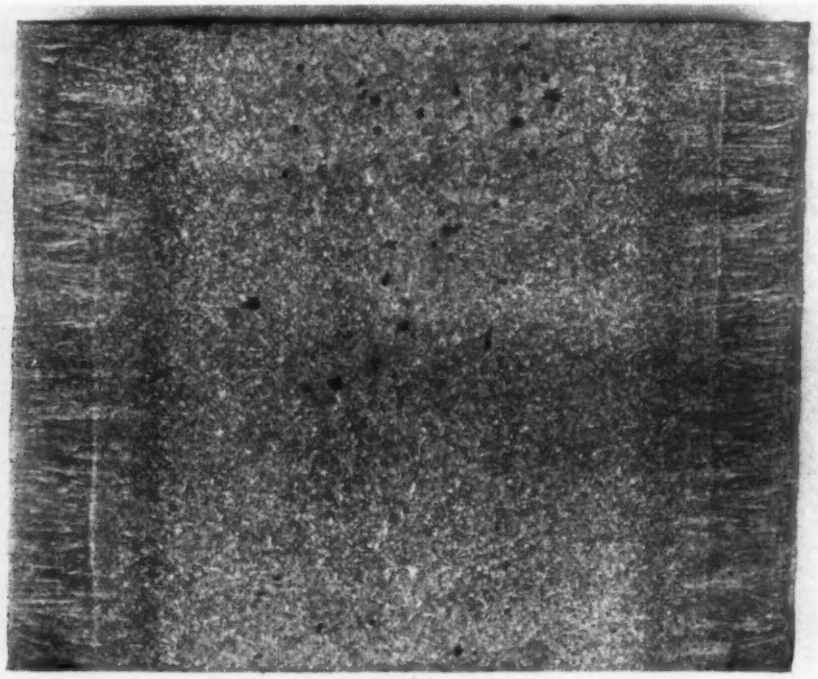

Fig. 70—Longitudinal section through broad central partition line of 6-in. × 2-in. slab of 18–8 Cr–Ni stainless steel

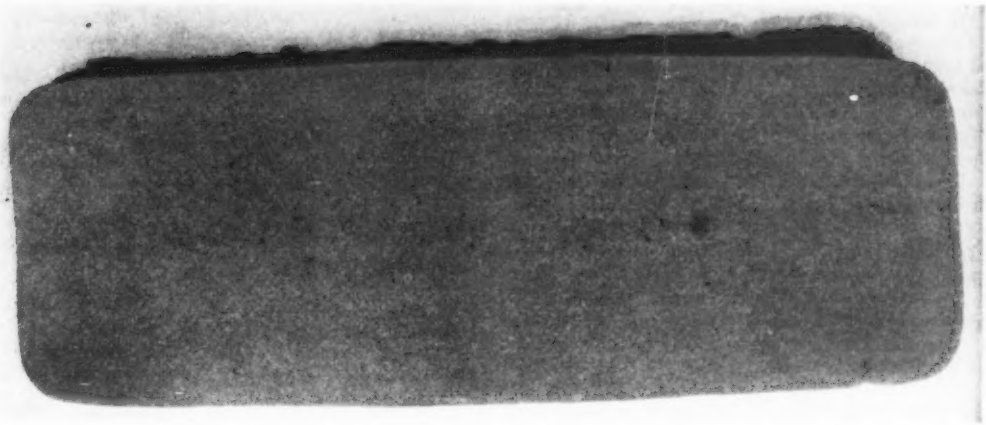

Fig. 71—Cross-section through 6-in. × 2-in. 0·55%C steel slab

third Term of Reference. A number of other considerations, however, are likely to attract increasing attention in the future:

(7) The product is delivered in hot continuous lengths and the potential for further savings is very considerable if production plants can be arranged to take full advantage of conserving the heat and of minimizing loss of yield in subsequent rolling processes.

(8) The possibility of delivering large or small tonnages of a given product at any time with a similar degree of economy can be arranged by having suitable quantities of metal brought, as required, to the machine.

(9) Because of the nature of the process, a scheduled furnace charge may well be tapped, cast, and delivered through to the re-rolling mills in a relatively short period, appreciably reducing overall works production time and allowing reductions not only in delivery time but also in capital investment for materials being processed.

(10) The process is well suited to the establishment of small tonnage plants whilst, at the same time, it can be planned to meet large production needs.

(11) Because of the relatively high casting speeds, and the long casting periods possible, the Barrow process is more suitable than others for use in conjunction with large OH steelmaking plants, even though operations with arc furnaces are generally more convenient, and preferable.

(12) The Barrow process, including horizontal discharge by bending, is capable of straightforward development to the production of thin (2-in.) slabs of considerable width, and therefore of contributing usefully to the manufacture of continuous sheet and strip.

Whilst the techniques for casting small sections developed at Barrow can be transferred to the casting of larger sections with corresponding advantages, most of the latter points listed above will not be proved until somewhere, sometime, production plants based on the full-scale use of continuous casting are established.

Acknowledgments

The author acknowledges his thanks for permission to publish this paper to The United Steel Companies Ltd. of Sheffield, at whose expense most of this work has been done. In particular, he thanks Mr G. N. F.

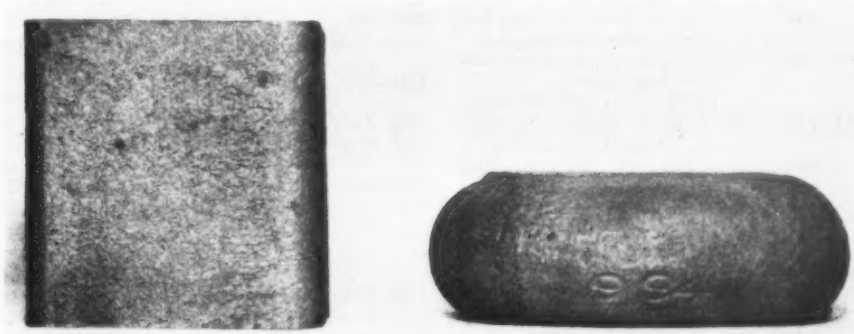

Fig. 72—Specimens of 2-in. square billet before and after hot upsetting under a steam hammer, showing good forging properties

Wingate and Mr F. H. Saniter, both of The United Steel Companies Ltd., for their individual and continued help and encouragement throughout the work. Special thanks are due to the Physics and Electronics Sections of The United Steel Companies Ltd., Research and Development Department at Rotherham, for their work in connection with the mould metal-level detection devices, and also to Mr Douglas Dixon of the same department for his work in preparing the photographs for this paper, and in helping to produce the two ciné films of the process.

Finally, the author would draw attention to, and thank, members of staff and works personnel at Barrow Steel Works Ltd. Led by Mr T. G. Marple, Mr J. Lyon, and Capt. W. F. Baily, their efforts helped to make this work possible.

APPENDIX

Historical summary of principal continuous-casting developments at Barrow

Date	*Trial no.*	*Section cast, in.*	*Brief description of development*
2nd Dec. 1952	1	3	First trial made
23rd Feb. 1953	26	2	2-in. square casting first attempted
2nd Mar.	30	2	Non-swirl nozzle proved advantageous
19th „	37	2	Combustion can preheating first established
29th „	39	2	Early attempt at automatic control
3rd Apr.	43	2	Casting first established at 150 in./min
13th „	45	2	Casting first established at 175 in./min
1st May	51	2	Casting first established at 200 in./min
5th „	54	2	Metal charge increased from 2 to 4 tons
29th „	66	2	Tapping temperature established at 1 600°C max. for 0·20%C steel
12th June	72	2	Tapping temperature established at 1 590° C max. for 0·20%C steel
1st July	81	2	First trial with tubular mould Discharge by tippler plate started
1st Sept.	104	2	Over 500 ft of billet first produced in one run
13th Nov.	146	2	Ladle drained empty for first time
5th Jan. 1954	177	2	Swing sprays first tried Nozzle blockage by Al_2O_3 deposits recognized
8th „	181	2	Use of negative strip established
12th „	183	2	First OH metal trial
25th Jan. to 24th Feb.	189 to 203	2	Trials with OH metal
19th Feb.	200	2	First trial of tubular mould with annular cooling passage Value of unrestrained mould tube flexing discovered
20th Feb.	201	2	First indication ladle can be emptied every cast
3rd Mar.	212	2	Casting continued about 1 h with 4-ton ladle
26th „	228	2	Ultrasonic tests on mould during casting
31st „	230	2	Over 1 000 ft of billet produced in one run
6th Apr. to 15th May	233 to 255	2	OH metal runs
11th June	267	2	First attempt at high-speed casting
17th „	272	2	OH metal cast at 325 in./min (average): ladle emptied
5th July	279	2	Ladle emptied at 405 in./min (average)
7th „	281	2	Ladle emptied at highest speed: 450 in./min (average) Max. speed attained: 570 in./min
26th Aug.	305	2	Last high-speed trial
14th Dec.	331	2	Suspended hollow-cone spray system established
28th Feb. 1955.	366	2	First 18–8 stainless steel cast
9th Mar. to 19th Mar.	368 to 377	2	Reliability trials: ladle emptied repeatedly, good product made
14th Apr.	391	2	First attempt to cast at 1 000 in./min
7th May	406	2	Last attempt to cast at 1 000 in./min
19th Aug.	410	2	Thin-wall mould first used
6th Sept. to 15th Sept.	415 to 418	6 × 2	Trials to establish casting of 6-in. × 2-in. slabs
21st Sept.	420	6 × 2	First 18–8 stainless slab cast: quality excellent
14th Nov.	438	3⅝	First 3⅝-in. square billet cast
22nd „	443	3⅝	Low-carbon steel (0·06% C) first cast
5th Jan. 1956	467	3⅝	Hard copper mould tube first tried
29th Feb.	493	2	Mould metal-level coil detector tests during casting
14th Mar. 1956 to 29th Jan. 1957	H.1 to H.29	2	Period of horizontal casting machine trials
21st Mar. 1956	495	2	Bending rolls established for horizontal discharge
7th May	506	2	Longest length billets (up to 139 ft long) produced
10th July	513	3	First 3-in. square cast using established process Bending rolls fitted with power cylinders
19th July to 11th Oct.	522 to 584	3	Production runs

Date	*Trial no.*	*Section cast, in.*	*Brief description of development*
29th Aug.	547	3	Use of aluminium wire feeder established to control grain size or to deoxidize mould metal
15th Nov. to 28th Nov.	600 to 616	3	Production runs
4th Dec.	622	3	3-in. billet cast at highest speeds; 185 in./min (average). Max. speed attained: 200 in./min
22nd Jan. 1957 to 31st Jan.	656 to 663	3	Reversed cam runs on 3-in. moulds
1st Feb. to 7th Mar.	664 to 693	3	1 : 1 ratio cam runs on 3-in. moulds
18th Apr.	694	3	First trial with 7½-ton ladle charge
29th ,,	695	6 × 2	First 6-in. × 2-in. slab cast using established process and bending rolls 7½-ton ladle drained empty
14th June	713	3⅝	Use of bending rolls established to discharge 3⅝-in. square billet
20th ,,	716	2	7½-ton ladle drained empty
26th June 1957 to 28th June	719 to 721	2	Long period runs: casting period of 1 h 56 min proved possible
1st July to 17th Sept.	722 to 750	2	Semi-production runs
9th July	725	2	First high-nitrogen valve steel cast
23rd ,,	731	2	Longest total billet length produced in one run: 1 449 ft (weight: over 8 tons)
26th Sept.	753	3	γ-ray equipment tests during casting
30th Sept. to 28th Oct.	754 to 773	2	Semi-production runs
31st Oct.	774	2	First equipment trials for γ-ray automatic control
21st Nov.	784	2	Automatic control casting established
22nd ,,	785	2	Complete cast run under automatic control
28th ,,	787	2	Alternative control equipment tests during casting

(End of single-strand machine operations)

Date	*Trial no.*	*Section cast, in.*	*Brief description of development*
6th May 1958	788	2	First twin-strand machine trial
6th June	792	2	7½-ton ladle drained empty on twin-strand machine
23rd ,,	803	2	First complete twin-strand cast under automatic control with self-start
23rd June to 18th July	803 to 839	2	Automatic control twin-strand reliability trials: 256 tons total produced in 37 casts, 98·5% overall average yield
14th Aug.	849	2	Attempt to cast 2-in. square rimming steel billet
21st Aug. to 22nd Aug.	852 to 853	2	High-nitrogen valve steel twin-strand runs
12th Sept.	863	3	Twin-stranding of 3-in. billet begun
19th ,,	869	3	Last cast before erecting large slab machine

Ingot surface-temperature measurement in forging furnaces

By J. R. Pattison

SYNOPSIS

A number of surface pyrometers designed to operate inside furnaces were tested and one instrument incorporating a reflecting hemisphere head, to correct for emissivity errors in surface temperature measurement, using the disappearing filament technique was found to be suitable for the temperature range of 800–1 300° C. Scale on the surface examined does not interfere with the operation of this pyrometer, which measures the metal surface temperature, and is in the form of a light portable quick-reading instrument.

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INTRODUCTION

THE SUCCESSFUL OPERATION of finishing and semi-finishing processes in the steel industry requires the heating of considerable masses of metal in furnaces of varying types to a reasonable uniformity of temperature throughout the charged material. The estimation of what constitutes a reasonable uniformity, other than complete soaking, at any given working temperature, can only be made by a series of tests. The performance of these tests has so far been prevented by theoretical and practical obstacles so that the regulation of heating periods for furnace charges has been made by rule of thumb methods with the consequent wasteful margins of safety causing a loss in the efficiency of operation. The most serious manifestation of this problem occurs in the forging furnaces involved in heavy forging processes.

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The author is on the staff of the Association's Plant Engineering and Energy Division.

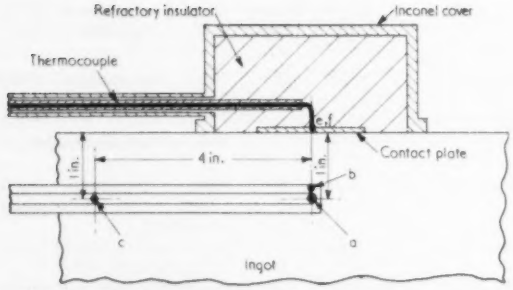

Fig. 1—Contact thermocouple surface pyrometer

The practical obstacle to the scientific regulation of heating periods has been the means of measuring the internal and surface temperatures of the stock. The former measurements can only be made by thermocouples inserted in holes previously drilled in the material and the most accurate measurement of the latter involves a similar procedure. The spoiling of the large and expensive ingots used for heavy forging cannot be undertaken as a regular check on the heating process and indeed is impracticable except as an exceptional measure.

The theoretical treatment of heat flow in steel under actual manufacturing processes was not possible until research was carried out by Sarjant and Hartree[1] over the period 1940–1944. Previous published work related to the simplified treatment of special cases. The work described by Sarjant and Hartree indicated that, for an ingot of given size of given material, the degree of uniformity in the temperature at the end of the soaking period depended almost entirely on the time required to heat the surface of the steel through the last 100° C and on the soaking time; the heating time at lower temperature had little effect on the soaking process. The relative simplicity of this relationship allowed Sarjant and Hartree to establish a simple formula connecting the soaking time necessary for a desired temperature uniformity, given the thermal properties of the steel, the size of the ingot, and provided that the heating time for the last 100° C rise of the surface temperature was known. Rough comparisons between the predictions of this formula and the normal soaking times employed in practice showed a considerable reduction in the latter to be possible. For this reduction to be effected a surface pyrometer was required, which would give accurate measurements during the last 100° C rise and which did not involve the previous preparation of the charged ingot before heating, so that routine check tests could be made on any ingot.

METHODS OF SURFACE TEMPERATURE MEASUREMENT

The most obvious methods applicable to surface temperature measurement are those depending on contact thermocouples, radiation detectors, or the disappearing filament principle. The main difficulties to be overcome in the use of thermocouples are the establishment of good contact with the surface and the avoidance of errors due to the conduction of heat along the thermocouple wires.

One solution is to weld the thermocouple junction to the surface and take the wires in insulators close to the surface, or better, to place the thermocouple and insulated leads in specially drilled holes as close as possible to the surface in the material under examination. These methods are not applicable where no special preparation of the ingot surface is possible and inside furnaces it is necessary to protect the thermocouple and wires from contamination and mechanical failure due to the action of the furnace gases.

Where the surface under examination is outside a furnace, radiation pyrometers or disappearing filament pyrometers can be used and the only source of error of any magnitude is that consequent upon the level of accuracy to which the appropriate surface emissivities are known. Inside furnaces this error is increased because the emissivities are less predictable and are, moreover, varying owing to chemical action on the surface. Further difficulties arising from the reflection of radiation from furnace flames and walls at a higher temperature and the absorption of radiation by the furnace atmosphere are also introduced.

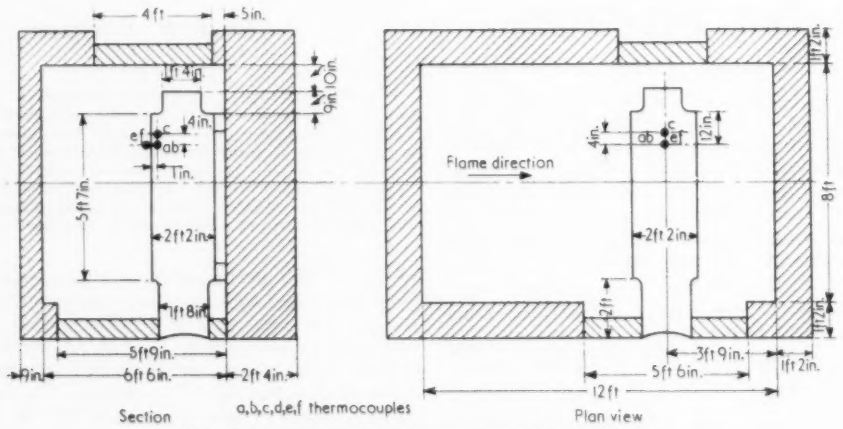

Fig. 2—Arrangement of thermocouples in furnace

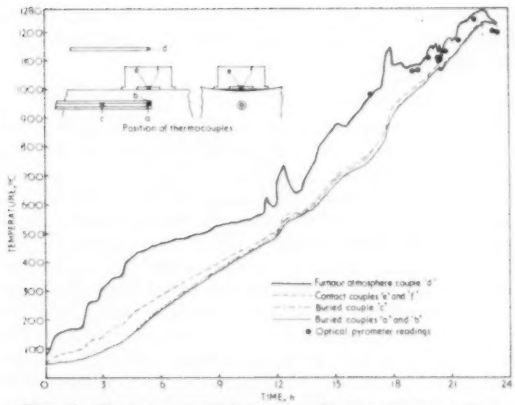

Fig. 3—Furnace and ingot surface temperatures

Contact thermocouple surface pyrometer

The protection of contact thermocouples inside furnaces by refractory cement is not difficult but to ensure a good contact more elaborate precautions are necessary. A device described by Land and Barber,[2] in which the measuring couple is peened into a 2-in² inconel plate, which is let into a refractory insulation brick 4 in. square and 2 in. deep contained in an inconel box, was tested on an ingot in a pulverized coal fired forging furnace. The diagram in Fig. 1 shows the position of the thermocouple junctions used: *a*, *b*, and *c* placed in a hole drilled into the ingot 1 in. from the surface and *e* and *f* peened into the plate. The wires from these thermocouple junctions were shielded from the furnace atmosphere by refractory insulators and a surrounding tube of heat resisting steel. The furnace temperature was measured by a further thermocouple in a refractory sheath placed above the contact pyrometer. Figures 2 and 3 show the locations of the ingot and thermocouples in the furnace and the temperature readings obtained. Temperatures measured by sighting a disappearing filament type optical pyrometer through a hole in the furnace wall on to one end of the ingot are also plotted.

These curves show that the contact pyrometer is strongly influenced by the furnace atmosphere so that, due to the conduction of heat through its refractory cover and imperfect contact with the ingot surface, a temperature reading is obtained 60° C above the true surface temperature of 100° C. This error diminishes at a greater rate than that at which the surface temperature approaches the furnace atmosphere temperature and at 800° C surface temperature, the contact pyrometer is reading only 28° C high.

The presence of the contact pyrometer causes a shielding effect on the ingot surface between 150° C and 1 100° C as shown by a comparison of the temperature given by the couples buried under the pyrometer and under an adjacent exposed surface of the ingot. However, the conduction error in the pyrometer itself and the shielding effect of the pyrometer on the ingot surface work in opposite directions so that it appears from the graph that the contact pyrometer reading above 800° C is exactly equivalent to the true surface temperature on an unshielded area of the ingot surface. Unfortunately the temperature at which the two errors become equal and opposite depends on the degree of good contact between the pyrometer and the surface, so that this cannot easily be predicted in advance. The ingot used in the trial was octagonal with concave surfaces so that the contact in this case would necessarily be worse than that possible on surfaces designed to be flat. However, at temperatures above 1 080° C the effects of internal conduction and shielding become small and the temperatures at the shielded and unshielded surfaces and the pyrometer temperatures are within a range of 8° C. It would appear that a smooth curve drawn through the pyrometer readings from 1 080–1 240° C could lead to a measure of the time of rise of the surface temperature through the last 100° C.

The high thermal capacity of the contact pyrometer makes it unsuitable for spot measurements of surface temperatures, and for the routine checking of the time of rise of the last 100° C in order to control the soaking time it would be necessary to place the pyrometer on to a flat horizontal surface of the ingot before heating begins.

Reflecting hemisphere pyrometer

Land[3] has designed a surface pyrometer in which a highly reflecting hemisphere is placed in contact with the surface. By multiple reflection of the radiation emitted by the hot surface a black body emitter is formed and the radiation from a small central hole in the hemisphere corresponds to black body radiation

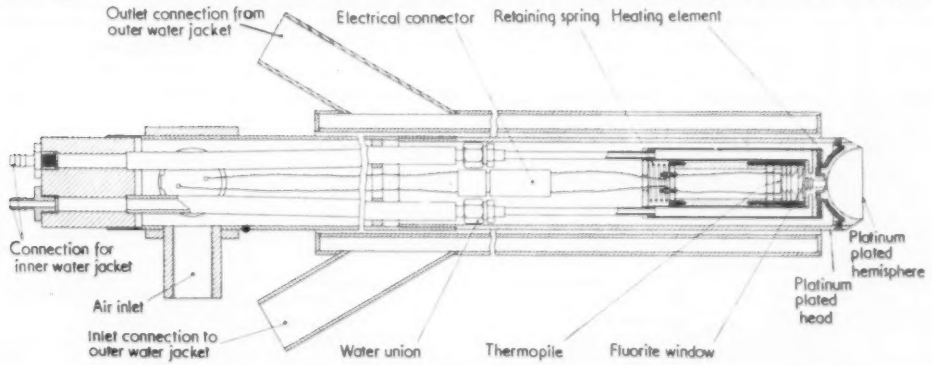

Fig. 4—Total radiation reflecting hemisphere pyrometer for use inside furnaces

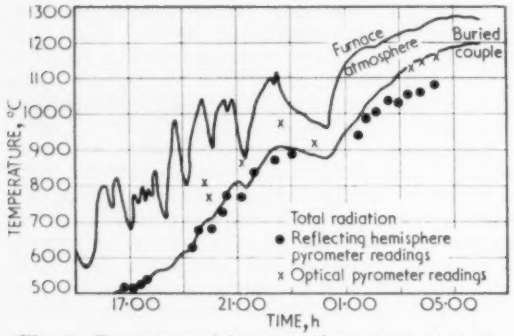

Fig. 5—Furnace and ingot surface temperatures

at the temperature of the surface. In its commercial form this instrument uses a thermopile to detect the radiation and a nickel shunt to compensate for changes in the cold-junction temperature. The instrument is portable, without water cooling, and not suitable for insertion into furnaces.

An instrument of this type, but designed for furnace work, was developed at BISRA and is illustrated in Fig. 4. The reflecting hemisphere and head were made of mild steel plated with platinum. The Moll thermopile was enclosed in a water jacket and protected from the furnace atmosphere by a fluorite window. The deposition of dirt or the condensation of water on this window were prevented by an air purge passing through the instrument and out of the central hole in the hemisphere. The body of the instrument was protected by a water-cooled jacket intended as a fixture in the furnace wall and extending to a point 3 in. from the ingot. The measuring head of the pyrometer was pushed out from the water jacket at intervals to make contact with the ingot under test. A heating element raised the hemisphere temperature to 220° C before each spot reading in order to prevent condensation resulting in possible damage to the highly polished surface. The pyrometer was calibrated against a disappearing filament pyrometer using a black body furnace as the transfer instrument.

Similar tests to that described for the contact thermocouple pyrometer were made in forging furnaces fired by both raw producer gas and pulverized coal. The vertical surface at one end of an octagonal-section ingot was used for measurements with a buried thermocouple to give comparative readings. A typical set of results is illustrated in Fig. 5. The pyrometer appeared to work well up to about 800° C but at higher temperatures a progressive deterioration in its performance occurs. This appears to be due to the instrument disturbing the furnace conditions and chilling the ingot surface.

Optical pyrometers

Optical pyrometers of the disappearing filament type are often used for routine checks on forging furnaces. However, as shown in Fig. 3, when sighted on to an ingot through a hole in the furnace wall the reading obtained is nearer the furnace atmosphere temperature than the ingot surface temperature, except during soaking when, with the difference between the furnace wall temperature and the ingot surface temperature at its minimum value and the fuel cut back, rather better conditions exist. The optical pyrometer readings shown in Fig. 5 were obtained by sighting the pyrometer down the water jacket of the reflecting-hemisphere pyrometer which extended to within 3 in. from the ingot surface. The improvement in the results is attributed to the screening of the pyrometer from most of the flame radiation. Good readings of ingot surface temperatures are obtainable by this artifice at high temperatures but at lower temperatures the successful use of the technique is dependent on varying furnace conditions. For example, in an oil-fired furnace where a reducing atmosphere was being used to prevent scaling, the water jacket merely acted as funnel for unburnt carbon particles which formed an opaque screen. A refractory tube which could be pushed into contact with the ingot and used for screening an optical pyrometer from gas radiation is a possible improvement on this method but has limitations in fragility.

Disappearing-filament surface pyrometer

The trials, described above, of instruments known to measure surface temperatures outside furnaces and redesigned to work inside furnaces, indicated that the disturbances of the temperature under investigation by the measuring instrument presented the main problem. There were further indications that this difficulty was increased by the presence of scale. Therefore laboratory investigations were made on scaled and unscaled surfaces both in and outside furnaces using the reflecting-hemisphere pyrometer, a disappearing-filament pyrometer, and a new design incorporating a hemispherical enclosure to correct for surface emissivity and a disappearing-filament pyrometer to measure the brightness temperature of the enclosure. This instrument is illustrated schematically in Fig. 6. The head and hemisphere is the same as that used in the instrument using a thermopile detector except that gold was used instead of platinum

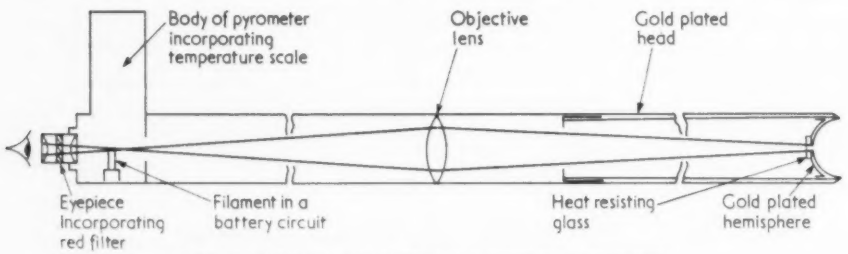

Fig. 6—Disappearing filament surface pyrometer

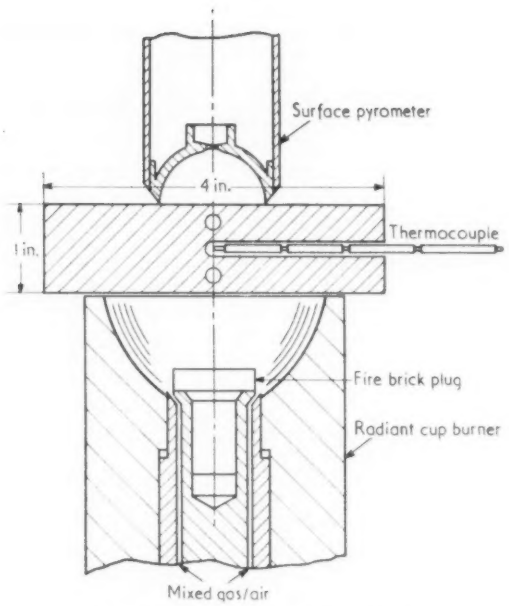

Fig. 7—Radiant cup burner tests

because the latter has a lower spectral reflectivity at a wave-length of 0·65μ. The hole in the hemispherical cavity was sealed by heat-resisting glass with good transmission properties at a wavelength of 0·65μ. The disappearing-filament device was made from a commercial instrument adapted by replacing the objective lens so that an image of the central hole of the hemispherical enclosure was produced at the filament. The instrument was calibrated against another standard disappearing-filament pyrometer by using a black body furnace.

For use in the furnaces the instrument was inserted in a water jacket fixed to the furnace wall and pushed into contact with the surface under examination for the short period necessary to obtain a reading. Only the plated head was exposed to the furnace atmosphere. The instrument is light, portable, quick

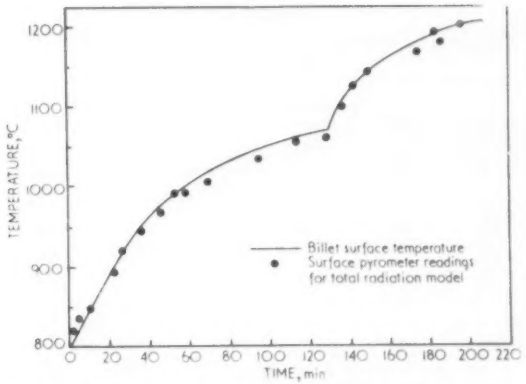

Fig. 9—Surface temperatures in billet furnace by total radiation surface pyrometer

reading and does not require a built-in water jacket or air purge.

LABORATORY TESTS ON STEEL SURFACES

In order to differentiate between the influence of furnace conditions and surface scale on the pyrometers, experiments on a hot surface in free air were set up. A 4-in. circular cross-section mild-steel plate of 1-in. thickness was placed on a radiant cup burner so that heating took place from one side only. The free side in air was thus available for surface pyrometer tests as shown in Fig. 7. The burner was fed with premixed gas and air and the temperature gradient on the axis of the plate was measured by three buried thermocouples inserted through 3 holes in the plate at angles 120° and at levels spaced at ¼-in. intervals so that the hot junctions were on the axis.

The furnace tests were carried out in the furnace illustrated in Fig. 8 which enclosed a mild-steel round billet containing five buried noble-metal thermocouples. Two were placed in the axis of the cylindrical billet with the junctions ¼ in. and ½ in. from the reference surface. The other three hot junctions were located on a circle of 1-in. radius about the axis at 120° intervals and at distances of ½ in., 1 in., and 1½ in. from the reference surface. The gas burner was so placed that the flame was near to the viewing hole

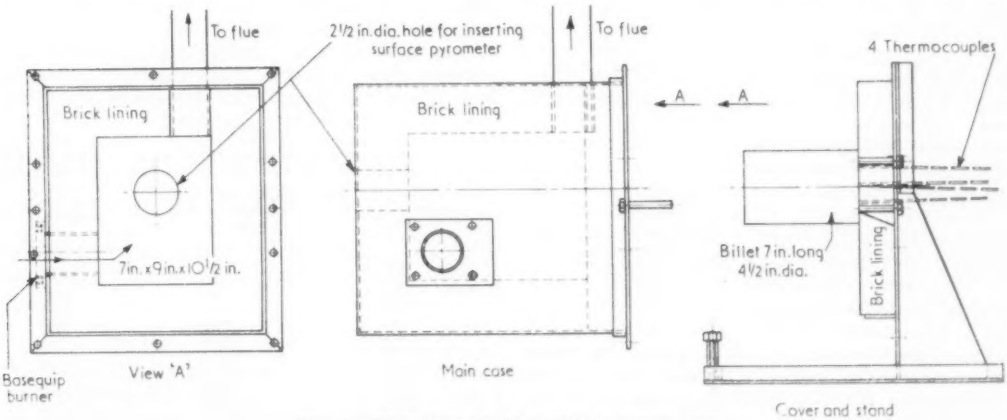

Fig. 8—Test furnace for surface pyrometer

TABLE I

Metal and scale surface temperatures for a free surface in air

Optical pyrometer reading, °C	Scale surface temperature, °C	Temperature drop across oxide, °C	Metal surface temperature, °C		
			Converted optical measurement	Surface pyrometer	Buried thermocouple
986	990	70	1 060		1 048
				1 053	1 050
978	981	60	1 041		1 030
				1 040	1 035
865	867	25	892		892
				902	897
872	874	26	900		904
				898	903
852	854	24	878		880
				890	889
874	876	Scale chipped off	876	879	877

and the end of the billet containing the thermocouple hot junctions. The pyrometers were thus tested under severe conditions of flame interference.

The reflecting-hemisphere pyrometer with the thermopile receiver was tested in the billet furnace using a combination of gas and air to avoid oxidation. Under these circumstances the instrument worked well over the 800–1 200° C range of surface temperature as the plotted results of Fig. 9 indicate, although a tendency for readings on the low side is apparent. To carry out tests with scale present on the billet surface an oxidizing atmosphere was used in the furnace and the billet was heated at 1 000° C for a period of time to allow scale to form before the temperature was reduced to 800° C and a heating cycle similar to that shown in Fig. 9 was begun. Under these conditions the total radiation reflecting-hemisphere pyrometer gave readings in error to about the same degree as illustrated in Fig. 5. Moreover there was a tendency for water to condense on the fluorite window and modifications of the air purge system and rate of air flow to prevent this caused even greater errors in surface temperature readings. It was apparent that the air purge cooled the outer surface of the scale so that the readings of temperature obtained did not correspond to those of the metal surface.

Tests carried out on the free hot surface of steel in air using heating by a radiant cup burner were made using a standard disappearing filament pyrometer, and the disappearing filament surface pyrometer. The disappearing filament pyrometer readings of apparent scale surface temperature were used to calculate the metal surface temperature using the values of emissivity and temperature gradient through the scale layer given by Burgess and Foote.[4] The results detailed in Table I confirm the values obtained by these investigators and their observation that the scale on steel tends to a constant thickness, and show the disappearing-filament surface pyrometer to give a

TABLE II

Surface temperatures of a billet heated in a gas-fired laboratory furnace

Disappearing filament surface pyrometer reading, °C	Buried thermocouple reading of surface temperature, °C	Temperature difference, °C
1 018 scale present	1 015	+3
1 133 ,, ,,	1 140	−7
1 291 ,, ,,	1 285	+6
1 243 ,, ,,	1 245	−2
1 127 ,, ,,	1 132	−5
1 115 ,, ,,	1 115	0
939 ,, ,,	932	+7
908 scale removed	907	+1
863 ,, ,,	866	+2
1 155 ,, ,,	1 157	−2
1 059 ,, ,,	1 060	−1
1 036 ,, ,,	1 035	+1
1 028 ,, ,,	1 027	+1
910 ,, ,,	909	+1
908 ,, ,,	906	+2
834 ,, ,,	831	+3
858 ,, ,,	858	0

measurement of the metal surface temperature in spite of the presence of scale.

In Appendix I a simple theoretical treatment is given of the process of temperature equalization in scale underneath the reflecting hemisphere. The limited thermal data available allow only an approximate calculation of the equalization time but this estimate shows the time to be less than the short time necessary to obtain a reading (10–15 s).

Tests of the disappearing-filament surface pyrometer in the billet furnace yielded readings of the metal surface temperature whether scale was present or not and typical values are shown in Table II.

Since the initial temperature gradients in the scale on the billet surface are unknown and variable during furnace heating it is not possible to calculate the equalization times under the hemisphere but the values in Table II indicate that equalization does occur within the time of measurement.

The performance of the disappearing filament surface pyrometer was tested in a forging furnace fired by raw producer gas, compared with a buried thermocouple and the temperatures shown in Table III were obtained.

Under the more exacting conditions of a forge shop it is not surprising that the range of the temperature differences in Table III is greater than in Table II. Some of this increased error may be due to the greater difficulty of ensuring a good flush contact between the pyrometer head and the ingot surface. It is shown in Appendix II that small gaps introduce negligible errors owing to surface radiation loss but, if the separation allows the penetration of hot gas streams or

TABLE III

Surface temperatures of an ingot in a forging furnace

Disappearing filament surface pyrometer reading, °C	Buried thermocouple reading of surface temperature, °C	Temperature difference, °C
800	806	−6
825	822	+3
943	934	+9
975	970	+5
1 045	1 048	−3
1 058	1 061	−3
1 104	1 107	−3
1 120	1 116	+4
1 123	1 129	−6
1 209	1 202	+7
1 234	1 230	+4

flame between the ingot surface and the hemisphere, then additional unknown errors are introduced.

The disappearing filament surface pyrometer was found to work well and to be unaffected by the presence of tightly adherent scale but the main limitations of the instrument are the deterioration of the gold reflective coating and the limiting temperature tolerated by the cement used to seal the heat resisting glass to the hemisphere aperture. At the end of the long series of tests in laboratory and works furnaces that was carried out with this instrument, the gold surface appeared dull but no alteration in the calibration of the instrument could be detected. The coating of the gold surface by oxides of silicon, as described by Hass and Scott,[8] would give a protection from the effects of heating, acid attack, and abrasion if this was found to be necessary. As a test of the robustness of the instrument head it was allowed to reach temperatures of 300° C in prolonged insertion in a furnace but no ill effects were observed. In the period of time of 15 s, or less, necessary for a reading, this temperature would not be attained in a forging furnace provided the head was cold before insertion. Care in allowing a sufficient cooling time between insertions would be necessary to avoid a progressive temperature rise of the head leading to possible damage.

CONCLUSIONS

A contact thermocouple surface pyrometer of the Land and Barber design is subject to considerable error as a result of its high thermal capacity and its shielding effect. These errors make the instrument unsuitable for spot measurements and for a routine checking of the time of rise of the last 100° C of surface temperature, the pyrometer must be placed on a flat horizontal surface of the ingot before heating commences.

A total radiation hemispherical surface pyrometer of the Land type redesigned for use inside a furnace requires a protective window which in turn necessitates the provision of an air purge to prevent deposition or condensation on it. In the presence of scale the cooling effect of the air purge causes malfunction of the pyrometer. Before scale becomes appreciable, up to about 800° C, the instrument operates well and gives a measurement of metal surface temperature. It is possible that the incorporation of an air purge shut-off device, operating as soon as the hemispherical head contacted the surface under examination, would make the instrument capable of metal surface temperature measurement in the presence of scale. However, the instrument, with water cooling and air purge, is already complicated enough and the associated instruments make it unsuitable for portable use so that this further additional device does not seem to justify extended investigation.

The disappearing-filament hemispherical-surface pyrometer has the temperature measuring part of the instrument outside the furnace and hence does not need water cooling. The monochromatic wavelength of operation allows the sealing of the hemisphere aperture with heat-resisting glass so that an air purge can be dispensed with and this allows the instrument to measure true metal surface temperatures even in the presence of a covering of scale. It is essential that the scale in question is strongly adherent to the metal surface for if loose scale forms the insulating effect of a pocket between the scale and the metal destroys the action of the pyrometer. However, loose scale can be cleared from the metal surface without difficulty before the pyrometer is applied so that this is not a grave limitation. It is concluded that this type of pyrometer provides a simple portable device which is a possible tool for the investigation of heating and soaking processes in forging furnaces.

Acknowledgments

The kind co-operation of the management and staff of Messrs William Jessop and Sons Ltd. and the English Steel Corporation, who provided the facilities at their works for many trials, is acknowledged.

APPENDIX I

The effect of the hemispherical reflector on surface temperature of scale

When a hemispherical reflector is placed in contact with a hot metal surface, heat transfer from the covered area to or from the external surroundings is prevented but, because of the relatively small part of the total metal surface which is affected and the high thermal conductivity of the metal, the surface temperature of the covered area is not significantly altered by a short time of contact. However, when the metal surface is covered by a layer of scale which is losing or gaining heat to the external surroundings, there can be a considerable temperature difference between the scale surface temperature and the metal surface temperature. Under these conditions when a hemispherical reflector is placed in contact with the scale surface the temperature gradient in the scale layer tends to diminish until the scale surface and the metal surface attain practically equal temperatures. Since the metal surface temperature is to be measured, not the scale surface temperature, and since the time of contact of the pyrometer is limited by considerations for its life, it is necessary to determine the time duration of the process of temperature equalization in the scale layer under the hemispherical cavity.

It is assumed that the thin chamfered edges of the hemisphere do not introduce appreciable cooling effects and that only a small proportion of the total area of scale is covered. Let the scale thickness be x and the metal surface temperature be T_2. The scale surface is assumed to be exposed in free air so that the temperature T_1 of such a surface is less than T_2. If the scale is tightly adherent to the metal surface it can be assumed that the flow of heat from the metal to the scale will not be impeded by unknown surface to surface conditions.

At a time θ after the hemisphere is placed in contact with the scale surface the scale surface temperature will have increased from T_1 to T. It is assumed that the metal surface temperature T_2 has remained unaltered because of the large mass of metal and its high thermal conductivity and that because the thickness x of the scale layer is small the heat transfer between the small disc of scale covered by the reflector and the uncovered surrounding scale layer is negligible. Hence, the time rate of heat transfer across unit area of the metal scale surface under the reflector is given by

$$\frac{\mathrm{d}Q}{\mathrm{d}\theta} = \frac{k\,(T_2 - T)}{x}$$

assuming a linear temperature distribution across the scale. Now with the same assumptions

$$Q = \tfrac{1}{2}\,\rho c_p x\,(T - T_1)$$

where ρ is the density of scale and c_p is the specific heat of scale.

Hence

$$\frac{dQ}{d\theta} = \tfrac{1}{2}\rho c_p x \frac{dT}{d\theta} = \frac{k(T_2 - T)}{x}$$

$$\therefore d\theta = \frac{\rho c_p x^2}{2k} \cdot \frac{dT}{(T_2 - T)}$$

Time for temperature equalization through the scale is

$$\theta = \int_{T_1}^{T_2} \frac{\rho c_p x^2}{2k} \cdot \frac{dT}{(T_2 - T)}$$

$$= \frac{\rho c_p x^2}{2k} \cdot \Big[\log_e (T_2 - T)\Big]_{T_2}^{T_1}$$

Since the scale surface temperature approaches the temperature of the metal surface asymptotically the temperature equalization time would be infinite. The time used in such cases conventionally is the response time corresponding to a temperature difference of $(T_2 - T_1)/e$ or $0{\cdot}368(T_2 - T_1)$. Using Burgess and Foote[4] if $T_1 = 1\,000°$ C then $T_2 = 1\,080°$ C so that the response time would relate to a final temperature difference of 29° C across the scale. This is larger than the error of the pyrometer so that the equalization time θ will be calculated for a remaining temperature difference of 1° C, i.e.

$$\theta = \frac{\rho c_p x^2}{2k} \cdot \log_e (T_2 - T_1)$$

From Kelley[5] the specific heats of the possible iron oxides at 1 040° C are FeO 0·20 cal/g, Fe_2O_3 0·16 cal/g, Fe_3O_4 0·18 cal/g. Hence a value of 0·18 cal/g will be assumed for the specific heat of scale on mild steel.

In the various experiments carried out as described in this paper the maximum scale thickness measured cold was 0·025–0·03 in. so x will be taken as 0·076 cm. The density of scale at room temperature was found to be 4·55 g/cm³.

Hence at $T_2 = 1\,080°$ C the relation between the equalization time θ and the conductivity of scale k is

$$\theta \,.\, k = 0{\cdot}008 \text{ cal/cm/}° \text{ C}$$

Unfortunately no published data for the thermal conductivity of scale are known to the author but if θ is put equal to 10 s, k becomes 0·001 cal/cm/s/° C, which is 1/67th of the value of the thermal conductivity of mild steel at 1 040° C as determined by the NPL.[6] This suggests that the time of temperature equalization is of the same order or less than the time required for a surface temperature determination.

APPENDIX II

Hemispherical reflector errors

Incomplete emissivity correction

If a closed hemisphere of spectral reflectivity r_λ is placed on a surface of spectral emissivity ϵ_λ the effective spectral emissivity E_λ of a small hole in the hemisphere is given by

$$E_\lambda = \frac{\epsilon_\lambda}{1 - r_\lambda (1 - \epsilon_\gamma)}$$

The true surface temperature T is then related to the brightness temperature S of the hemisphere hole by the relation

$$\frac{1}{T} - \frac{1}{S} = \frac{\lambda \log E_\lambda}{C_2}$$

Where λ is the wavelength of the pyrometer and C_2 is a constant of Planck's equation. T and S are in ° K.

Hence $$\frac{1}{T} - \frac{1}{S} = \frac{\lambda}{C_2} \cdot \log_e \left(\frac{\epsilon_\lambda}{1 - r_\lambda (1 - \epsilon_\lambda)} \right)$$

The reflectivity of gold varies with temperature so assuming at worst a hemisphere temperature of 300° C, $r_\lambda = 0{\cdot}92$ at $\lambda = 0{\cdot}65\mu$ using values obtained by Worthing.[7]

By Burgess and Foote,[4] if $T = 1\,200°$ C, for oxidised iron $\epsilon_\lambda = 0{\cdot}92$.

Hence $E_\lambda = 0{\cdot}993$ and $S = 1\,199{\cdot}3°$ C so that due to incomplete emissivity correction, an error of less than 1° C is introduced at a surface temperature of 1 200° C. At lower temperatures the error is lower still.

Finite hole size

If the radius of the axial viewing hole in the hemisphere is r and the hemisphere radius is R, the proportion of the monochromatic radiation emitted by the surface covered by the hemisphere which escapes through the hole without reflection is $(r/R)^2$. The effect of this loss can be expressed in the form of a modified spectral reflectivity $[1 - (r/R)^2]r_\lambda$. Now in the instrument described $r/R = 3/40$ and $E_\lambda = 0{\cdot}9927$ for $T = 1\,200°$ C which introduces an additional error of $-0{\cdot}05°$ C into the value of S. Thus the error resulting from both imperfect reflection and the size of the aperture used, is of the order of 1° C at an oxidized steel surface temperature of 1 200° C.

Incomplete contact

If the hemisphere is not in contact with the surface under examination a further error is introduced through the loss of radiation between the hemisphere rim and the surface. The proportion of the monochromatic radiation emitted by the surface directly under the hemisphere which escapes through a small gap of width d is $d^2/(R^2 + d^2)$. However, the area under the hemisphere is only a small part of the larger area of the object under test and for a body cooling in free air the remaining surrounding area acts as an infinite guard ring radiating through the gap into the hemisphere an equal amount of radiation to that lost. Due to multi-reflection under the hemisphere however the exchange of radiation through the gap will not be equal and opposite, for the enclosed area will radiate as if its emissivity were unity. Hence a proportional net loss through the gap

$$\frac{d^2 (1 - \epsilon_\lambda)}{R^2 + d^2} \text{ will occur.}$$

A further complication is introduced by the equalization of temperature across the scale layer beneath the hemisphere so that the surface temperatures inside the enclosure rise from T_1 to T_2 while the 'guard ring' surface remains at the temperature T_1. When equalization is complete the net proportional loss is

$$\frac{d^2 \left[1 - \epsilon_\lambda \exp \frac{C_2}{\lambda}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)\right]}{R^2 + d^2}, \; T_1 \text{ and } T_2 \text{ in } °\text{K},$$

and the equivalent hemisphere spectral reflectivity is further modified to

$$\left[1 - \left(\frac{r}{R}\right)^2 - \frac{d^2}{R^2 + d^2} + \frac{\epsilon_\lambda d^2}{R^2 + d^2} \cdot \exp \frac{C_2}{\lambda}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)\right] r_\lambda$$

At $T_2 = 1\,200°$ C with a gap $d = 1/16$ in., evaluation of this expression yields a value $0{\cdot}988 r_\lambda$ so that $E_\lambda = 0{\cdot}9921$ and $S = 1\,199{\cdot}2°$ C. Thus a 1/16 in. gap of complete separation added to the other sources of error does not introduce a total error greater than 1° C at a surface temperature of 1 200° C.

If the hemisphere made contact at one point on the rim then a gap of twice this value, that is $\frac{1}{8}$ in. at the point of maximum separation, would introduce the same numerical error. When the pyrometer is used for surface temperature measurement on an ingot inside a furnace, the effects of imperfect contact may be less because the radiation from the hotter walls and the flame would be reflected through the gap and give increased compensation for radiation loss. However, such gaps should be avoided as much as possible if there is any possibility of flame or hot gas entering the hemispherical enclosure by this means.

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Letter to the Editor

The deposition of material in slag pockets and regenerators of open-hearth furnaces

THE THERMAL EFFICIENCY and melting rate of modern open-hearth furnaces could be greatly improved by increasing the preheat in the combustion air. Such increases may be brought about either by raising the convection coefficient from brick to air in the regenerator (by employing narrower flues) or by rendering the distribution of air and waste gases more uniform over the whole checkerwork.

All such improvements, however, will be nullified by the deposition of material carried over from the melting bath, and so it would seem that other approaches should be made.

First, the slag pocket could be redesigned to increase its collecting efficiency, and thereby permit changes in the regenerator. Secondly, if the former method proves unsuccessful, there should be evolved an entirely new method of preheating the air and cooling and cleaning the waste gases.

The material deposited in the checkerwork and slag pocket varies in chemical and physical properties, according to its origin and subsequent history. From accumulated data,[1] the size distribution was stated to approximate to 50% of total weight less than 5μ and 50% of total weight greater than 50μ, with virtually nothing in the intermediate size ranges. The chemical analysis usually shows more than 50% Fe_2O_3 and Fe_3O_4, taken together, and the concentration in the downtake is of the order of 1 grain/ft^3.

The slag pocket is intended to remove this material by gravity settling, but, owing to its orientation with respect to the gas stream, a certain amount of rotation is imparted to the gases. Using a 1/10 scale cold-air model, an effort was made to improve the collection efficiency of the slag pocket by increasing the amount of rotation and centrifugal separation.

The model (Fig. 1*a*) approximated to the largest one-way cyclone that could be installed into the space occupied by the slag pocket of a particular open-hearth furnace. Similarity in the model and original was ensured, first in the motion of the fluid by equating Reynolds numbers, and secondly, in the motion of particles, by making the particle number* equal.[2] A 3-g amount of cork particles of 250μ size, whose particle number was equal to that for 100μ iron-oxide particles, was injected into the downtake by compressed air over a period of 1 min. The collecting efficiency was measured by fastening an oiled greaseproof paper liner to the inside of the circular portion of the model, and weighing it before and after the injection. The method was repeatable and accurate to 3%.

The behaviour of molten sticky particles in a furnace is represented here by dry particles impinging on a sticky surface, because dry particles would be prevented from remaining in such a system by an axial component of velocity, acting towards the outlet.

After trying several modifications of the model, one of the more practical versions of which is shown in Fig. 1*b*, it was found that the highest efficiency achieved was nearly 60%. A direct comparison was then made, using the same technique on a 1/10 scale model of the existing slag pocket of the furnace, mentioned above, and an efficiency of 40% was recorded.

*P = Particle number = $\dfrac{3\pi\eta L_0 D}{mV_0}$

where m = mass of particle
D = diameter of particle
L_0 = characteristic length in the system
V_0 = characteristic velocity in the system
η = viscosity of gas.

This presupposes Stokes' law of resistance to hold for the particle motion.

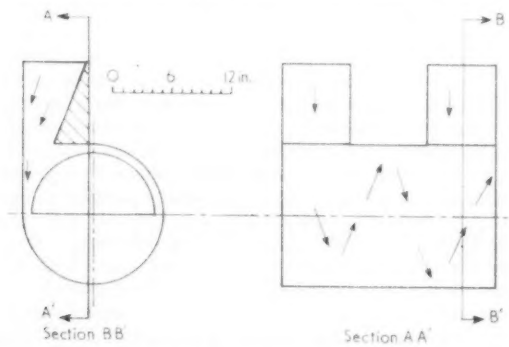

Fig. 1*a*—1/10 scale slag pocket with one vortex. Direction of flow as shown

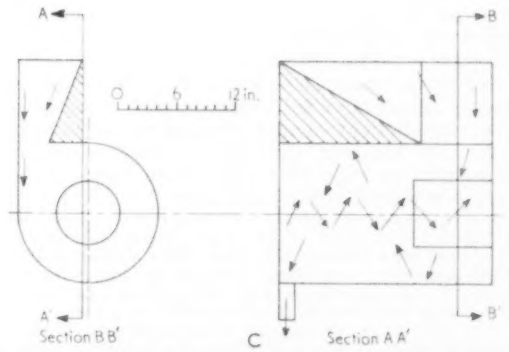

Fig. 1*b*—1/10 scale slag pocket with two vortices. Separated material and 10% of gas led off at *C*. Direction of flow as shown

If the stated particle size analysis applies, it is to be concluded that

(1) Little benefit will be gained by substituting a one-way cyclone, such as that described above, for the conventional slag pocket in the open-hearth furnace;

(2) A new design of such a system to give a two-way cyclone (Fig. 1*b*) would not deal effectively with a high proportion of fine material, and would cause rotation and bad distribution in the space above the checkerwork.[3]

It would seem that the best method of dealing with such a material would be to retain the existing slag pocket, designed for minimum turbulence and the most efficient gravity settling to deal with the coarse fraction, and to use an easily replaceable granular filter bed to remove fine particles from the outgoing waste gases and to preheat the combustion air. Initial experiments with such a bed have shown high collecting efficiencies.[4]

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The behaviour of various elements in vacuum steelmaking

By G. M. Gill, A.Met., L.I.M., E. Ineson, B.Sc., F.I.M., and G. Wesley Austin, O.B.E., M.Sc., F.I.M.

SYNOPSIS

The quality of steels produced by vacuum processes may depend partly on the extent to which various residual elements are removed from the melt during processing. Available vapour-pressure data suggest that several impurities known to occur in steels could be distilled preferentially from the liquid metal under vacuum. Small-scale vacuum-melting experiments have been undertaken to verify this supposition. It has been found that manganese, copper, tin, zinc, and lead can be almost completely removed and chromium, arsenic, and sulphur partially removed by vacuum-induction melting. Silicon behaves in a way that cannot yet be explained. Nickel, molybdenum, and phosphorus contents are virtually unaffected by vacuum-induction melting. In vacuum-arc consumable-electrode melting, the tendencies are similar but do not occur to the same extent as in induction melting. 1663

THERE IS a growing interest in vacuum methods of steelmaking and information is required about the effects of these methods of manufacture on the quality of steels produced by them. The emphasis of much of the work reported so far has been related to the degassing effects of vacuum treatments, and only recently has attention been devoted to other compositional effects. It is not unlikely, however, that some of the improvements or changes in properties of steels, brought about by vacuum treatment, could be explained by a change in the balance of residual elements remaining in the steel. A study of available vapour-pressure data suggests that several elements commonly found in steels in trace amounts (e.g. tin, copper, lead, antimony, etc.) might be partially or almost wholly removed by preferential distillation from the melt under vacuum; indeed, this may prove to be the only technique applicable for the removal of some of these elements. There is already sufficient information in the literature to suggest that the removal of such elements could have an important effect on the properties of steels and certain other alloys of importance to the steel industry.

This paper presents the first stage of an experimental survey of some of the compositional changes that can occur during vacuum melting of ferrous materials. Attention has been directed to elements normally considered as impurities and also to some elements generally classed as alloy additions.

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Mr Gill is a member of the Metallurgy (General) Division Staff at Sheffield, where Mr Ineson is Head of Laboratories; Professor Wesley Austin is the Division's Consulting Supervisor.

Thermodynamic considerations

The bulk of the literature available on vapour pressures of liquid metals is devoted to the pure elements, and it appears that little experimental work has been done on the behaviour of elements in dilute solution in iron. It is possible, however, by making various assumptions about the activities of the various elements, to derive approximate values for the vapour pressures of elements in solution in iron.

Several of the important alloying elements are so similar to iron with respect to atomic size and other properties that it seems reasonable to assume that they form nearly ideal solutions and will obey Raoult's law. In this group are manganese, chromium, cobalt, and nickel. This assumption is further justified in that no intermetallic compounds are formed and each element has a wide range of solid solubility. Many elements form definite chemical compounds with iron and, while it is probable that such compounds lose their identity in liquid solution, the chemical attraction between iron and the element persists in the melt. This gives rise to a negative deviation from Raoult's law. In this group are silicon, aluminium, titanium,

TABLE I
Thermodynamic data for pure elements under consideration

Element	Atomic No.	Atomic weight	Melting point, °C	Boiling point, °C	Approx. vapour pressure at 1600° C (pure element), mm Hg	Approx. vapour pressure in 1% solution in iron at 1 600 C, mm Hg	
						Assuming ideality	Using known activities
Be	4	9·02	1 280	2 770	1·44	0·0086	...
B	5	10·82	2 300	...	0·58	0·00295	...
C	6	12·01	3 700	4 380	79×10^{-4}	...	...
Mg	12	24·32	640	1 110	> 760	...	...
Al	13	26·97	660	2 060	16·7	0·035	0·0015
Si	14	28·06	1 430	2 300	0·98	0·0035	0·00006
Cr	24	52·01	1 890	2 500	1·55	0·0017	0·0017
Mn	25	54·93	1 242	2 150	25	0·25	0·25
Fe	26	55·85	1 539	2 740	0·10	...	...
Co	27	58·94	1 495	2 900	0·0097	0·000090	0·00009
Ni	28	58·69	1 455	2 730	0·099	0·00094	0·00094
Cu	29	63·54	1 083	2 600	1·03	0·0091	0·11
Zn	30	65·38	419·5	906	> 760	...	...
Se	34	78·96	220	680	> 760	...	...
Zr	40	91·22	1 750	...	0·00005	3×10^{-4}	...
Nb	41	92·91	2 415	...	...	...	...
Mo	42	95·95	2 625	4 800	8×10^{-7}	...	...
Cd	48	112·41	321	765	> 760	...	...
Sn	50	118·70	232	2 270	1	0·0047	...
Sb	51	121·76	630	1 440	760	...	...
Ce	58	140·13	600	...	1	0·004	...
Pb	82	207·21	327·4	1740	400	0·88	...
As	33	74·9	sublimes at 610 C		>760	...	...

zirconium, and boron. Positive deviation from Raoult's law is found in the alloys of iron and copper. The atoms of these two metals appear to repel one another, and there is a tendency for the melt to separate into two solutions; this is assisted by the presence of a small percentage of carbon. These deviations from Raoult's law must be considered in the calculation of the vapour pressure of solutions, as the effect can be considerable, particularly in complicated alloys.

Table I lists some of the more common elements, with thermodynamic data, including vapour pressures calculated in accordance with the above assumptions. These are based mainly on data provided by Kelley[2] and by Brewer.[3] In some instances quite large discrepancies were found in the published data, and in these cases the value most widely quoted by other authorities was adopted.

The vapour-pressure data shown in Table I support the suggestion that several impurities known to occur in steels could be removed preferentially from the melt by suitable vacuum treatment. Clearly, the amount evaporated will be very much influenced by the temperature and time of treatment, and by the order of vacuum used. The form of the melt (i.e. whether treated as a liquid bath or as small droplets) will also play an important part.

TABLE II
Effect of vacuum melting on high-purity binary alloys

Element, %	Time, min						
	0	5	10	20	40	60	90
Mn	0·6	< 0·01	< 0·01	< 0·01	< 0·01	< 0·01	< 0·01
Cr	0·63	0·58	0·54	0·51	0·51	0·51	0·51
Pb	0·94	0·021	0·011	0·005	0·003	0·002	0·002
Cu	0·92	0·27	0·08	0·014	0·005	0·004	0·002
P	1·13	...	...	...	...	...	1·10
Si	0·75	0·70	0·68	0·60	0·58	0·57	0·58
Ni	1·05	...	...	...	...	...	1·10
Sn	0·81	< 0·01	< 0·01	< 0·01	< 0·01	< 0·01	< 0·01
Zn	0·62	< 0·01	< 0·01	< 0·01	< 0·01	< 0·01	< 0·01

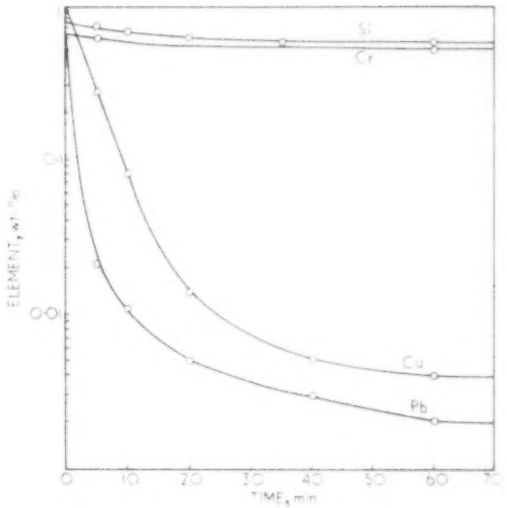

Fig. 1—Change in composition with time

Experimental results

Preliminary experiments have been carried out on a small scale in a vacuum-fusion gas-analysis apparatus described by Speight and Gill.[1] The equipment is capable of reaching a temperature of 2 000° C and a vacuum of 10^{-6} mm Hg, but it can also be used for the much lower temperatures and vacua encountered in industrial vacuum plants. Samples of about 100 g of steel were melted in cylindrical alumina crucibles of

TABLE III
Effect of vacuum melting on composition of Ni–Cr–Mo steel

Element, %	Initial	Vacuum-induction treated	Consumable-electrode arc-melted
Si	0·25	0·36	0·29
Mn	0·48	< 0·01	0·38
Cr	1·30	0·97	1·27
Ni	4·4	4·9	4·5
Mo	0·18	0·20	0·18
Cu	0·28	< 0·01	0·25
V	< 0·01	< 0·01	< 0·01
Ti	< 0·01	< 0·01	< 0·01
W	< 0·05	< 0·05	< 0·05
Co	< 0·01	< 0·01	< 0·01
Sn	0·026	< 0·01	0·017
Pb	0·186	< 0·01	0·071
Hardness (H_D30)	344	360	400

TABLE IV
Effect of vacuum melting on high-tin steel

Element, %	Initial	Vacuum-induction treated
Si	0·21	0·21
Mn	< 0·01	< 0·01
Cr	< 0·01	< 0·01
Ni	0·013	0·015
Mo	< 0·01	< 0·01
Cu	0·028	< 0·01
V	< 0·01	< 0·01
Ti	< 0·01	< 0·01
W	< 0·05	< 0·05
Co	< 0·01	< 0·01
Sn	1·76	0·0056
Hardness (H_D30)	230	75

about 3 cm diameter and 2·5 cm deep, suspended in the field of an h.f. coil by molybdenum wires. The melt has a surface area of about 8 cm^2 and a depth of 2 cm. The evaporated material is condensed on to a cold surface of 1 500 cm^2 at a minimum distance of 1 cm from the metal surface.

To assess the reliability of the calculated vapour pressures and to obtain information about simple systems, a series of binary alloys containing up to 1% of residual or alloying elements were manufactured. Table II gives the original composition of these alloys, which were treated for times of 5, 10, 20, 40, 60, and 90 min at a vacuum of 1 μ and a temperature of 1 600° C and the residual metal in the crucible was carefully analysed. The results of this series of experiments are shown in Table II and represented graphically in Fig. 1. As would be expected from the vapour-pressure data shown in Table I, Mn, Pb, Cu, Sn, and Zn are eliminated very rapidly from the melt, certainly within the times normally used in vacuum melting;

TABLE V
Effect of vacuum melting on a high-arsenic steel

Element, %	Initial	Vacuum-induction treated	Consumable-electrode arc-melted
Si	0·26	0·30	0·27
Mn	0·59	0·03	0·45
Cr	0·032	0·028	0·030
Ni	0·15	0·17	0·16
Mo	< 0·01	< 0·01	< 0·01
Cu	0·13	0·044	0·12
V	< 0·01	< 0·01	< 0·01
Ti	< 0·01	< 0·01	< 0·01
W	< 0·05	< 0·05	< 0·05
Co	0·011	0·012	< 0·01
As	0·126	0·104	0·116
Sn	0·037	< 0·01	0·024
Hardness (H_D30)	143	116	171

TABLE VI
Effect of vacuum melting on high-sulphur free-cutting steel

Element, %	Initial	Vacuum-induction treated	Consumable-electrode arc-melted
Si	< 0·01	< 0·01	< 0·01
Mn	1·10	< 0·01	0·9
Cr	0·58	0·42	0·057
Ni	0·086	0·09	0·086
Mo	0·029	0·039	0·028
Cu	0·13	< 0·01	0·12
V	< 0·01	< 0·01	< 0·01
Ti	< 0·01	< 0·01	< 0·01
W	< 0·05	< 0·05	< 0·05
Co	< 0·01	< 0·01	< 0·01
Sn	0·14	< 0·01	< 0·01
S	0·33	0·15	0·30
Hardness (H_D30)	127	180	131

Cr and Si are only slightly reduced over a 90-min period, and P and Ni are not affected at all.

A series of steels approximating to commercial materials have also been vacuum-induction treated at 1 600° C for 90 min at a pressure of 1 μ. It is appreciated that this time is longer than would generally be used in practice, but it gives an indication of the refinement that can be obtained with vacuum-induction melting. These same materials have also been vacuum-arc-melted at a pressure of about 4 μ by a consumable-electrode process giving a 1-in. dia. ingot. Tables III[5]–VII give the results of these experiments with steels. These results are in general agreement with those from the binary alloys, with the notable exception of Si in the Ni–Cr–Mo steel (Table III) and the arsenic steel (Table V). Cu, Sn, Pb, and Mn are

TABLE VII
Effect of vacuum melting on mild steel

Element, %	Initial	Vacuum-induction treated	Consumable-electrode arc-melted
Si	< 0·05	< 0·01	< 0·05
Mn	0·79	< 0·01	0·54
Cr	0·05	0·04	0·04
Ni	0·12	0·13	0·12
Mo	0·02	0·02	0·02
Cu	0·32	< 0·01	0·24
V	< 0·01	< 0·01	< 0·01
Ti	< 0·01	< 0·01	< 0·01
W	< 0·05	< 0·05	< 0·05
Co	0·013	0·015	0·014
As	...	...	...
Sn	0·04	< 0·01	0·04
Hardness (H_D30)	120	170	137

almost completely eliminated by h.f. vacuum-induction treatment. Cr is slightly reduced and the melt is enriched in Ni and Mo owing to preferential evaporation of Fe. The arc-melted results show a similar sort of change, though not to the same extent as vacuum-induction melting, and there is certainly no elimination of undesirable elements. This is perhaps understandable, since the time of treatment is short and the order of vacuum lower than for the induction treatment.

In all vacuum-induction experiments the fume condensed on the cold surface over the melt has been collected and is being analysed.

CONCLUSIONS

With the exception of silicon, the elements examined behaved in accordance with expectation from vapour-pressure data on the pure elements.

Manganese, copper, tin, zinc, and lead may be almost completely removed during vacuum-induction melting. The major part of the evaporation of these elements was found to take place over the first 5 min of the treatment. Chromium, arsenic, and sulphur are partially removed down to some apparently constant value. Silicon also behaved in this way in a binary iron–silicon alloy, but not in a more conventional steel composition. Nickel, molybdenum, and phosphorus were unaffected by vacuum-induction melting.

Vacuum-arc consumable-electrode melting appears to affect only the more volatile elements such as manganese, copper, tin, and lead, though not to such a great extent as vacuum-induction melting.

Acknowledgments

The authors are most grateful to Mr K. Speight and his colleagues in the Analytical Section of BISRA for undertaking the analysis with great skill and care. Dr J. Pearson has been most helpful in his advice on the thermodynamic considerations. Experiments on vacuum-arc melting were carried out with the kind cooperation of Edwards (High Vacuum) Ltd.

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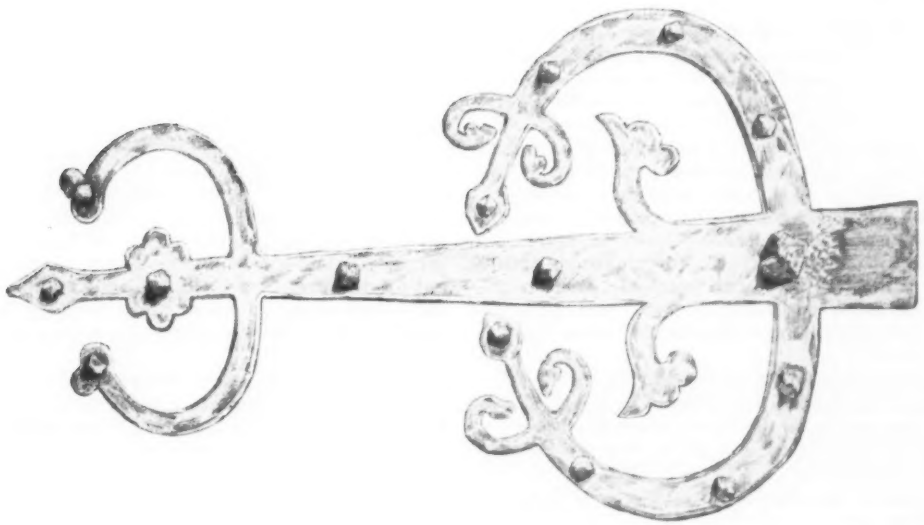
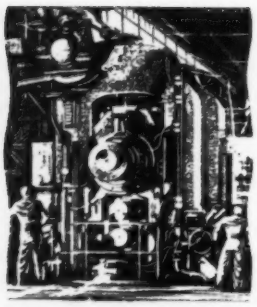
Sussex

Ecclesiastical Ironwork — IV

Our illustration shows a ride or hinge strap on the west door of the parish church of St Mary, Sullington.

The church itself is largely Early English, from the first half of the thirteenth century. The massive oak doors at the west end are richly embellished with wrought ironwork of an early pattern, of which the illustration is a representative example.





IRON AND STEELWORKS ENGINEERING

The Iron and Steel Engineers Group

Remote position control of screwdown drives of primary rolling mills

SUMMARY OF AN INTERIM REPORT

By L. N. Bramley, F. Seredynski, L. J. Chant, and G. K. Steel

INTRODUCTION

THE INCREASING COST of labour and materials and the trend to increase efficiency has led to an acceleration in co-ordination of control of industrial processes. In an advanced stage this development may be called automation, or the intelligent replacement of the human operator by automatic processes.

A vast majority of the industrial processes in a steelworks consist of moving masses, either of product or plant, through finite distances, and before any of these movements can be automated, a thoroughly efficient technology of automatic position control as applied to steelworks is required. It was felt that a promising starting point for the development of such a technology would be the primary rolling mill.

The controls of the auxiliaries of a primary rolling mill are used to move each of the different parts of the mill, e.g. upper roll or manipulator, from one position to another and it seems natural to expect the controller handle to be moved in a related manner. In fact, in most controls of this type, a movement of the control handle does not result in a corresponding change in position of the object being moved. The handle merely sets velocity, a continuously increasing displacement, which is watched and integrated by the operator until it reaches the position required. If necessary, he makes velocity corrections during the integration, and he must always use his judgement as to when to stop. The great disadvantage of this form of control is that, whilst judging position and velocity, the operator is fully occupied and the attention he can spare for manipulation of other controls is very limited.

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The authors are with the Association's Battersea laboratories.

With remote position control (r.p.c.) a discrete displacement of a control causes a corresponding displacement of the output and use of such a control can result in both saving of time and improvement of uniformity of product. Time is saved because the automatic control brings the plant to the required position, at the maximum speed and without overshoot, every time, and precision is improved because the machine can achieve a greater consistency of accuracy in routine settings than an operator can in the time available. Another advantage is that the operator is freed from routine duties for a substantial proportion of his time, so that he is more alive to the possibility of an emergency. Finally, position control opens the way to programming any sequence of operations in plant such as rolling mills, and thus is an essential step towards full automation.

The idea of using position control on auxiliary drives is not new, since any limit switch device is a form of position control and these have been used on both crane and mill drives for many years.[1] Exploration of the situation both in the United States and in Europe[2] revealed that a multi-limit switch positional control of mill screwdown had been available from the US manufacturers since 1927 and several US mills incorporating this feature were installed, mostly in the USA, but also in Europe. One of these installed in the North of England is still giving satisfactory service; indeed it is claimed that but for its screwdown position control feature it would have been scrapped years ago. As it is, it is still making steel plate on a competitive basis with the new continuous mills.

In spite of the apparent effectiveness of early mills fitted with remote position control, progress was slow. In the USA the multi-limit switch arrangement gave way to a well designed, vernier-adjusted single potential divider scheme.[3] This first appeared in 1936 but was not taken up on a wide scale until comparatively recently. It has, however, now been installed

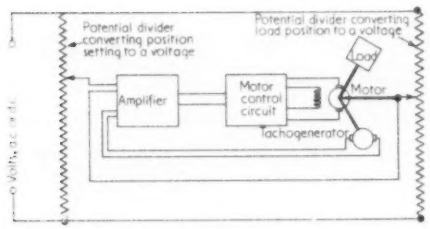


Fig. 1—Basic analogue scheme of remote position control

on many primary mills there. The actual control units involve precision engineering and by British standards the scheme is very expensive. Other schemes are also in operation in the USA which are sound in principle but expensive. It is doubtful if UK steelworks would have installed such expensive drives in the absence of operational data.

Most of the US installations incorporate two alternative preset programmes of screwdown, and generally one of these is being set up whilst the other is in use. This is not ideal for several reasons. An extra operator is required and the arrangement appears to be inadequate to deal with unforeseen variations of ingot temperature and with combined variations of ingot and finishing size, steel composition, and roll behaviour.

To overcome this lack of flexibility, the electrical companies are now installing punched card programming schemes in certain mills. Opinions on these at present are very mixed and only time will show whether they will produce the further advantages expected. The 'translator'[4] may well be a more satisfactory alternative on the score of flexibility.

OBJECTS OF THE INVESTIGATION

To explore the possibilities of remote position control applied to primary mill screwdowns and to see how far the advantages listed above could be borne out by experiment, it was decided to develop comparatively inexpensive and simple schemes which could be applied to both existing contactor-controlled d.c. drives and new Ward-Leonard schemes. It was also decided to vary the details so as to gain as wide an experience as possible.

Basic control scheme

Position indicator schemes

In any remote position control scheme signals proportional to the desired and actual positions are

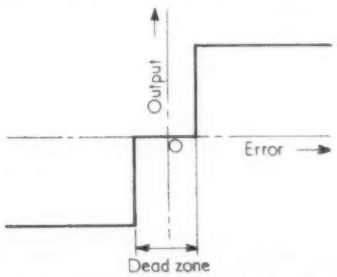


Fig. 2—Basic characteristics of discontinuous error amplifier

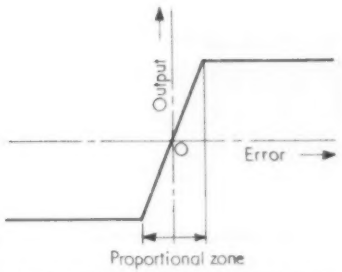


Fig. 3—Basic characteristic of continuous error amplifier

compared and the difference is amplified to effect a correcting action. There are two common ways of doing this, namely, by means of synchros, which are essentially a.c. devices, and by means of potential dividers.

The potential-divider position-indicator scheme with moving-coil polarized relays is much simpler than the corresponding synchro scheme. Direct current may be used and the signal is exactly proportional to displacement in the potential divider, whereas it varies sinusoidally in the synchro and this has a limiting effect on system design. No reason has been found to preclude the use of potential divider error detection if a.c. is used. The systems described in the present report all use potential dividers but this must not be construed as in any way condemning the use of synchros.

Systems in which control is effected continuously are known as 'analogue' systems, but systems in which control occurs in steps, are known as 'digital' systems. One basic analogue scheme for providing position control of a mechanism is shown in Fig. 1. It uses a potential divider as a position detector on the machine and compares the voltage tapped off it with a reference voltage set on an input potential divider. As long as these voltages differ significantly the difference will be amplified and used to energize the motor which will run so as to reduce the difference voltage.

Control systems of interest in the present context may be classified into two main types:

(i) Discontinuous or 'on-off' systems
(ii) Continuous systems.

Discontinuous systems

The term 'discontinuous system' describes a system in which the amplification has an output–input relationship of the form shown in Fig. 2, which is characteristic of the operation of a polarized relay arrangement, the input to which is often a current in the coil and the output the current through change-over contacts. The relay arrangement may consist of a centre-stable moving-coil relay or of a pair of single-contact relays preceded by an electronic detector stage.

The limited load capacity of the contacts on these sensitive relays makes further amplification necessary. This is done by using the contacts to operate another relay with contacts of higher rating. By using further relay stages it is possible to operate the large starter-panel contactors as the final output stage and so control a large motor. This cascade arrangement of

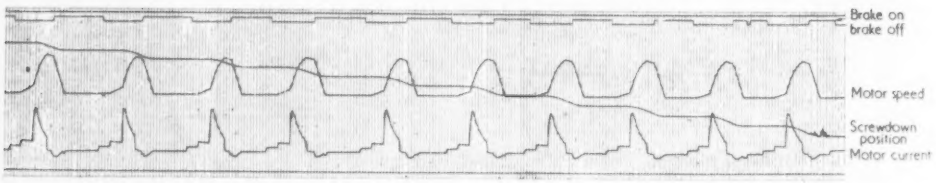


Fig. 4—Oscillograph record on a remote position controlled motor on laboratory test bed

relays is called a relay amplifier. An amplifier of this type may be inserted into a closed-loop system as shown in Fig. 1 and connected so that the polarized relay is operated by the error signal. Whenever the error voltage exceeds that required to make one of the polarized-relay contacts close, the motor contactors are energized and the motor will run in such a direction that the error voltage is reduced. Thus the system will come to rest only when the error is less than that required to operate the polarized relay and the total relay amplifier 'dead band' therefore determines the accuracy of the final reset position.

Continuous systems

In installations where the motor control circuit is of the Ward-Leonard type as distinct from a contactor system, considerable advantage can be derived from using a system incorporating linear amplification of error. The distinctive feature of the Ward-Leonard type of circuit which makes this effective is that by supplying the exciter field from a proportional amplifier, the speed of the controlled motor will be proportional to the error signal. The variation of output with error is shown in Fig. 3. With a contactor-controlled motor this proportional relationship cannot be achieved since there are only a limited number of discrete speed settings. The advantage of maintaining a proportional control relationship lies in the ability of the system to maintain a high setting accuracy down to the final point of stopping so that marked overshooting or undershooting is avoided, even when the load is varying.

System operation and velocity feedback

Due to inertia and to control-circuit time lags, the motor will not stop immediately the difference voltage is brought to zero so that, without some form of compensation, the load will travel past the required setting point and a correction in the opposite direction will follow. Under certain conditions this process can be continued indefinitely and appears as an oscillation of the motor. This oscillation can be eliminated by providing the system with a signal which will enable it to anticipate the approach of the required setting point and cut off or reduce the motor supply at such a value that the motor stops at the setting point. A signal dependent upon speed as derived from a tachogenerator (velocity feedback) can provide anticipation of this nature, and its introduction into the basic circuit is illustrated in Fig. 1.

Types of amplifier

The error amplifier may be a relay amplifier, an electronic amplifier, a magnetic amplifier, or a rotary amplifier (e.g. metadyne), or a combination of these, the choice being governed by the requirements of amplification, gain stability and absence of zero drift, power output capacity, transient response, and reliability.

Where a high gain is required at high power output, such as in a screwdown position control, a very good arrangement consists of a high-gain electronic a.c. amplifier followed by a rectifier which, in turn, feeds a magnetic amplifier or rotating amplifier. For use as an error amplifier, it is necessary for the rectifier section to be phase sensitive, so that a reversal of the phase of the amplified a.c. signal will cause the rectifier output to change polarity.

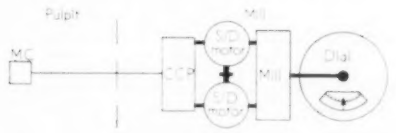
PRELIMINARY LABORATORY TESTS

The first opportunity to install a remote position control of screwdown arose in a works having a contactor-controlled screwdown motor. Before installing equipment on the mill, however, preliminary tests on a remote position control of related size were carried out in the laboratory. A 50-h.p. mill-type contactor-controlled motor was equipped with an 18-in. brake wheel arranged for normal braking duty and with a 24-in. brake wheel, modified and water cooled, to supply a continuous loading torque. This torque was adjustable and, during the tests, was arranged to load the motor to about 20 h.p.

A permanent-magnet tachogenerator was chain-driven from the motor at the load brake-wheel end and a selsyn unit, mechanically coupled to a small double generator to act as a self-excited tachogenerator, was driven from the motor at the 18-in. brake-wheel end.

The selsyn was used as part of a 'flexible shaft' to drive a similar selsyn mounted in a dial unit. This drove, through a gear box, a pointer on a large dial to give simulated screwdown position and also drove the output potential divider. A second pointer was controlled by means of a handwheel through another pair of selsyns in a manner similar to that in the mill installation and this handwheel also turned the input potential divider.

The large dial was calibrated from 0 to 30 in. of



C.C.P. Contactor control panel
M.C. Master controller
S.D. Screwdown

— Mechanical shafts
— Electrical connections

Fig. 5—Standard contactor control scheme for rolling-mill screwdown

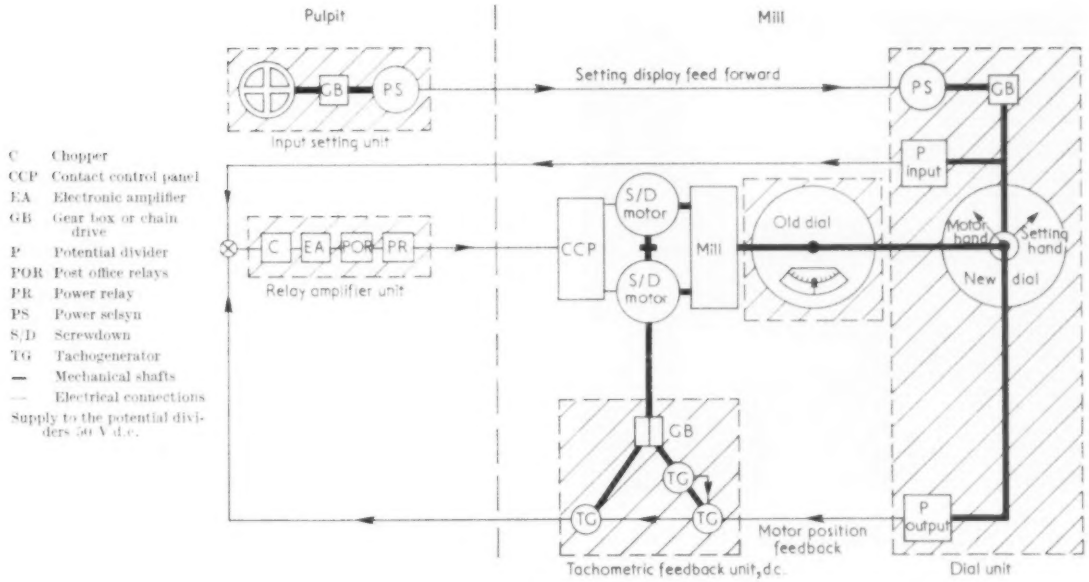


Fig. 6—Proposed analogue r.p.c. scheme for rolling-mill screwdown with handwheel

screwdown to simulate conditions at the rolling mill where the trial was to be carried out.

The laboratory system presented a very fair approximation to the proposed steelworks installations and it was found easy to adjust so that, for all increments of screwdown above about 1 in., it ran up to full speed and shut down from full speed to stop at the correct reading on the dial. The accuracy attained was of the order of $\pm \frac{1}{32}$ in. in 30 in., i.e. about 1 part in 1 000.

Figure 4 shows oscillograph traces of motor current, motor speed, brake operation, and screwdown position taken on the system for a sequence of steps of screwdown of 2 in. In this series of tests no oscillation, undershoot, or overshoot was experienced. It is not claimed that these did not occur, but when the system was properly warmed up and correctly adjusted, divergencies from the optimum were infrequent enough and small enough to be negligible.

This mock-up screwdown drive served a double purpose. It provided a working system and display for demonstrating the principles of remote position control to a considerable number of interested steelworks engineers; and it formed a basis for development which has proved invaluable over the last two years.

WORKS INSTALLATIONS

Considerable development work has been done on three installations which has necessitated frequent modifications. The systems finally employed, or recommended, are briefly described together with the more important results of development work carried out on earlier schemes.

The three systems consist basically of the units shown in Fig. 1. The motors and the motor control circuit constitute the basic screwdown-drive system which, before modification to provide position control, were operated through a master controller in all three installations. The significant differences between the three r.p.c. systems are in the types of input signals and in the types of motor-control circuits used. The other units were designed to the particular requirements of each installation, except for the output detector which was of the same basic form in all three installations.

INSTALLATION AT STEELWORKS *R*

The screwdown motors of the cogging mill at steelworks *R* are predominantly shunt wound, of 80 h.p., and are contactor-controlled in the usual way by master controller from the control pulpit. Position of screwdown is displayed on a dial mounted on the mill housing.

Requirements

The final remote position control requirements at steelworks *R* were as follows:

(i) To provide a position control on the screwdown motors which could be preset and, upon actuation, would set itself to any point in the screwdown travel with an inaccuracy not exceeding $\pm \frac{1}{16}$ in. in 30 in. i.e. to about 1 part in 500. The new control was not to reduce the maximum operating speed of the screwdown drive which is of the order of $2\frac{1}{2}$ in./s

(ii) To provide for presetting to be eliminated so that the drive followed up the position of the setting device as soon as the latter was moved towards a new position

(iii) To provide for a change back to ordinary (velocity) control in case the new control gave trouble, and also so that a comparison between velocity and position control could be made. It was essential for this changeover facility to be continuously available and practically instantaneous.

In later discussions it became apparent that it was also desirable to reduce the speed of the motor at

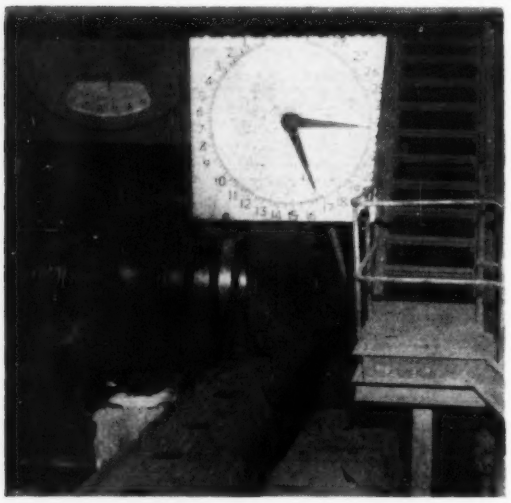


Fig. 7—Early mill screwdown dial unit and dials

both ends of the drive while under remote position control, so that it could not accidentally run into the stops in the event of a circuit failure.

Originally the steelworks asked for presetting by means of a continuously varying handwheel in the mill pulpit, but they have recently decided that push-button control should be tried. The final handwheel scheme has many points of general application whenever a continuous handwheel input is desirable.

Proposed analogue scheme for steelworks *R*

Figure 5 shows the conventional contactor-controlled arrangement for the screwdown motors and the full proposed analogue remote position control scheme is shown in Fig. 6. The scheme follows orthodox lines for a continuously variable potential-divider scheme except that the input-feed forward control is outside the main loop and thus does not introduce any misalignment errors, and the velocity feedback unit is a multiple generator arrangement. The control console consists simply of an 18-in. handwheel and shaft coupled through a 6–1 step-up ratio to a power selsyn. Rotation of the handwheel and power selsyn causes another power selsyn on the screwdown dial display unit to rotate and a pointer on the dial, driven by this second selsyn through a 1–6 step-down ratio, rotates with the handwheel. The input potential divider is also set from the pointer shaft.

The existing mill indication of screwdown setting is by means of a rotary dial and stationary pointer. This construction was adopted by the mill manufacturers because the view of the upper part of the mill from the pulpit is obscured by a crane gantry girder, and consequently there is no location available for the installation of a normal moving-pointer dial. This added considerably to the practical difficulties of installing remote position control. It was finally decided to couple the old dial, mechanically, to a pointer on the new dial and to provide this new dial with the required setting pointer as shown in Fig. 7. The final design incorporates a dial with two pointers, on concentric shafts. The inner shaft bearing the front pointer, painted black, is connected directly to the output potential divider to indicate screwdown

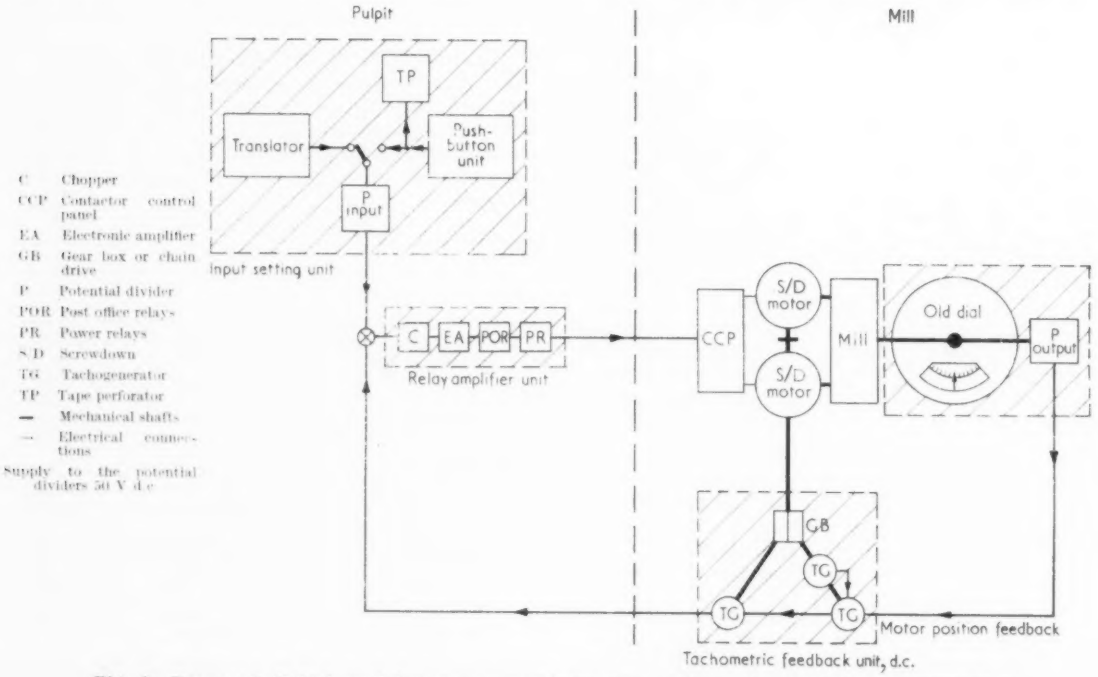


Fig. 8—Proposed digital push-button or translator r.p.c. scheme for rolling-mill screwdown

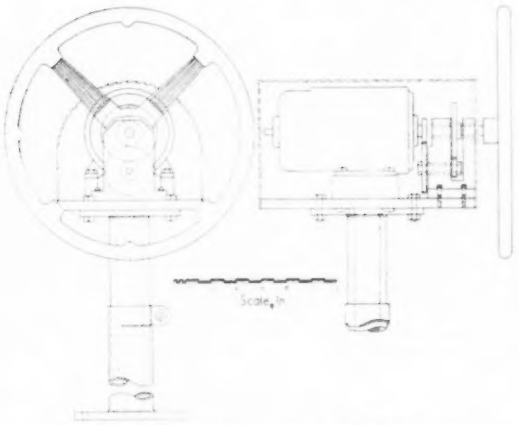


Fig. 9—Input setting unit, handwheel type

position and also to an extended shaft on the old dial via a totally enclosed high-grade spiral bevel gear drive between the dial centres. The outer shaft bearing the rear pointer, painted red, indicates required position and is connected to the input potential divider and power selsyn through appropriate gear boxes. Hermetic sealing with full glanding for all emergent shafts of the dial unit is recommended.

The dial face is of thick plywood 5 ft 6 in. dia., painted white with a scale and numbers following ergonomic principles. It is brilliantly lit by a ring of 60-W bulbs shielded so that the bulbs themselves cannot be seen from the pulpit. Special protection of the lamp sockets to prevent ingress of dirt is provided.

An electronic amplifier is used which consists of a chopper electronic amplifier feeding a twin-channel cascade relay amplifier giving the effect of a two-speed control via the main contactor panel. The cabinet houses this amplifier together with the protective relays and auxiliary controls for initial adjustments.

In an on-off servo of this kind it appears to be necessary to supply tachometric feedbacks proportional to both the output velocity and to the square of this velocity. Strictly this squared component should be expressed as $V|V|$ to take account of sign.

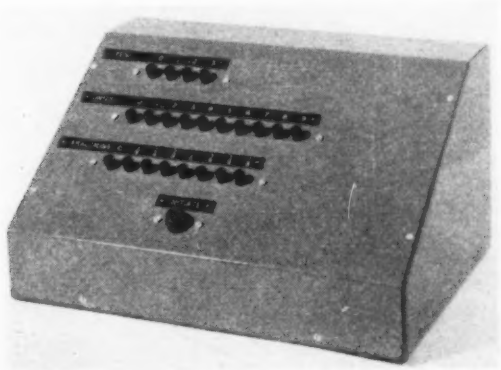


Fig. 10—Input setting unit, push-button type

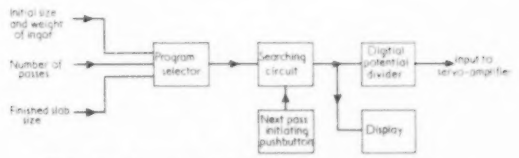


Fig. 11—Input setting unit, translator type

Simple velocity feedback is obtained from a permanent-magnet d.c. tachogenerator of orthodox design and the velocity-squared component from a special tachogenerator having a double armature and two fields. A voltage generated in one winding of the armature by virtue of a permanent magnet field is fed to a wound second field and the resulting voltage at the second armature brushes thus varies as the square of the armature velocity. Both instruments are very robust and designed for steelworks use, and the second one was developed by the makers specially for the requirement outlined above.

The two tachogenerators are mounted on a robust bed-plate and, although the point on the mill where the drive can be taken up is not critical, it is best effected at one screwdown motor shaft. A good arrangement is to equip a motor extension shaft with a long gear pinion and mesh the two tachogenerators direct to this. Any endplay in the screwdown motor shaft can then do no damage to the tachogenerators. This is a very important point since as much as $\frac{1}{4}$ in. of end play has been experienced on screwdown mill-type motors of modern construction during this investigation and this has proved destructive to directly coupled auxiliary equipment.

Extensive experimental work on the mill installation was concerned with finding the best take-off points in the system for the various feedbacks required in the control and in determining the best method of detecting the error signal. Owing to the practical difficulties, e.g. that the dial of the rolling mill was of the rotating disc type, that operating conditions were arduous, and that the mill was being operated on an 18-shift week and was thus only available for short periods, the optimum scheme was not arrived at at once and several alternative arrangements were tried.

The final system described (Fig. 6) incorporates all the knowledge gained on handwheel systems during trials lasting several months, and should assist any engineer contemplating the installation of such a system although it is yet untried as an entity.

In an earlier installation, a moving-coil relay detector stage was used instead of the chopper amplifier and the position feedback unit was actuated using a power selsyn unit instead of directly. The range of usefulness of the moving-coil polarized relay was explored in some detail and it was concluded that, in almost all cases where accuracies of the order of 1 part in 500 are required, it could be bettered by some form of electronic detector, but for accuracies of the order of 1 part in 100 the moving-coil system was suitable and even attractive.

The cascade relay unit was originally housed in the mill pulpit and the closing and opening of the main contactors was clearly audible to the operators who would not start to roll until these relays had stopped

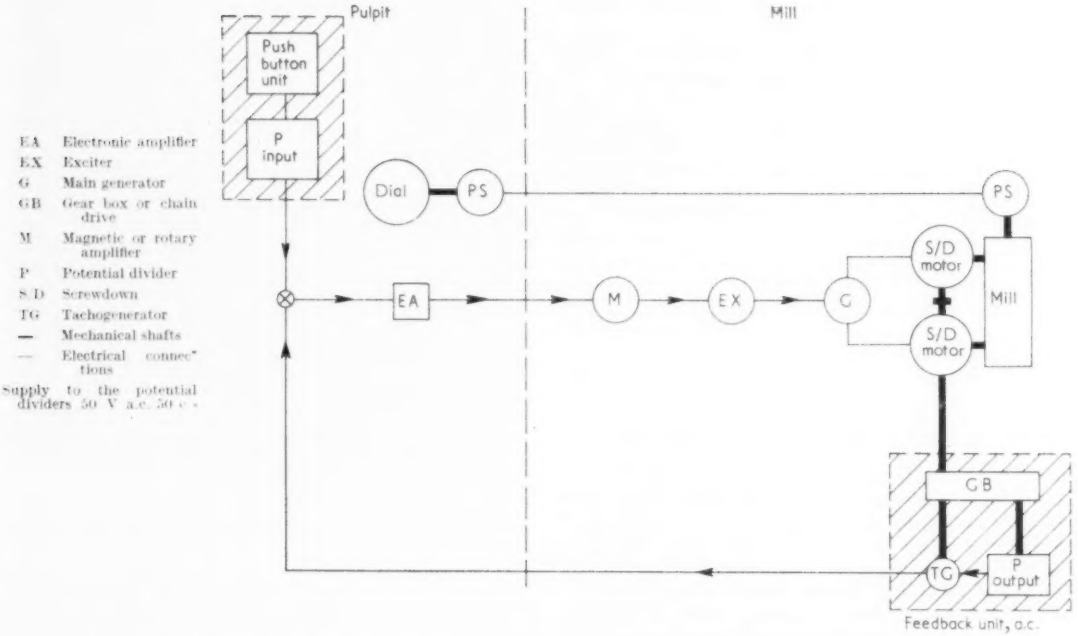


Fig. 12—Proposed digital r.p.c. scheme for rolling-mill screwdown with pushbutton control

operating; in many cases the movement of the pointer was so small at these times that it could not be seen and certainly did not provide a reason for holding up rolling. The general trend was to make the control seem slower than it was. In the final recommended scheme the cabinet is situated outside the pulpit.

Proposed digital schemes for steelworks *R*

Steelworks *R* have recently decided that they prefer a pushbutton r.p.c. scheme on their screwdowns instead of the handwheel scheme, and a suitable scheme has now been designed and is represented in diagrammatic form in Fig. 8. The amplifier, tachometric feedback, and position feedback units are retained but the input handwheel unit shown in Fig. 9 is replaced by a pushbutton console (Fig. 10) and a translator with a changeover switch so that either can be selected.

With the pushbutton console in use, each draft is set up in tens of inches, inches, and eighths by pressing the requisite buttons. Pressing the master button then starts motion of the screws to the new setting. In fact depressing the setting buttons produces a voltage proportional to the desired setting of the screws and this is fed into the servo input in the usual way.

Use of the pushbuttons is proposed for unusual rolling programmes which only account for a small portion of the total programmes. For fully routine programmes the translator is brought into operation and the operator's task is reduced to setting up the known input data on selector switches, e.g. size of ingot, number of passes, dimensions of finished bloom or ingot etc., and operating the 'next pass' button. The translator input unit is shown diagrammatically in Fig. 11, but, for full understanding of the translator principle, reference should be made to the companion paper on the subject.[1]

A new dial is not required with a digital scheme, and the existing dial serves only to reassure the operator that the intended setting has been reached.

INSTALLATION AT STEELWORKS *A*

The screwdown motors of the cogging mill at steelworks *A* are shunt wound, of 200 h.p., and are controlled by means of a master controller of orthodox construction which controls the field of a 3-field generator supplying the motors.

Requirements

The remote position control requirements at steelworks *A* were to provide a position control on the

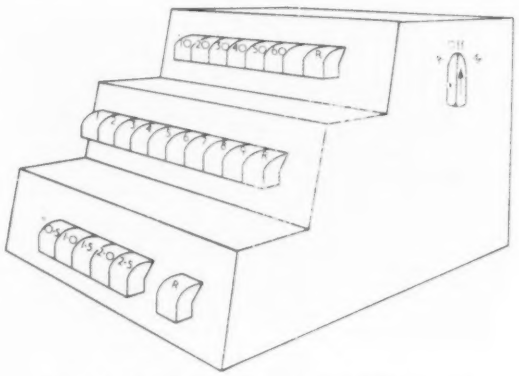
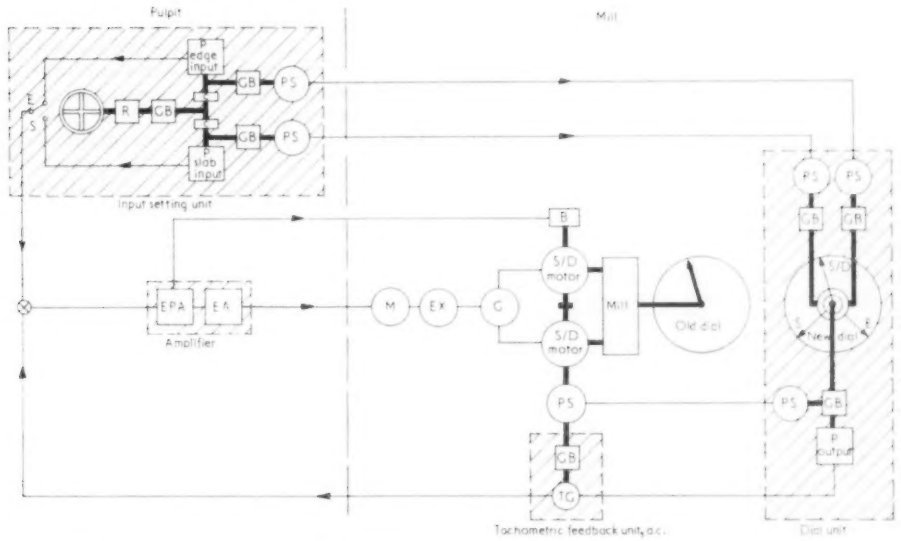


Fig. 13—Input setting unit, pushbutton type



B	Brake	G	Main generator	S	Slab
C	Magnetic clutch	GB	Gear box or main drive	S/D	Screwdown
E	Edge	M	Magnetic or rotary amplifier	TG	Tachogenerator
EA	Electronic amplifier	P	Potential divider	—	Mechanical shafts
EPA	Electronic preamplifier	PS	Power selsyn	--	Electrical connections
EX	Exciter	R	Ratchet	Supply to the potential dividers 50 V a.c. 400 c/s	

Fig. 14—Proposed analogue–digital r.p.c. scheme for rolling-mill screwdown with ratchet handle

screwdown motors which, upon actuating push-buttons, would set itself to any point in the screwdown travel with an inaccuracy not exceeding $\pm \frac{1}{8}$ in. As the maximum screwdown opening is about 70 in. this means an accuracy of 1 part in 500. The new control was not to reduce the maximum operating speed of the screwdown drive which is of the order of 6 in./s. Screwdown change was to be effected by draft increments where possible, and not by roll gap settings; all controls were to be by pushbutton. Five draft steps were required from $\frac{1}{2}$ in. to $2\frac{1}{2}$ in. in steps of $\frac{1}{2}$ in.

Proposed digital scheme for steelworks *A*

The scheme is shown diagrammatically in Fig. 12 and it follows reasonably orthodox lines for a servo-mechanism having continuous measurement and correction of error. Thus it is appreciably different from the contactor-controlled schemes for steelworks *R* (Fig. 6) and this difference is made larger by the choice of components and operating supplies in order to gain as wide a range of experience as possible.

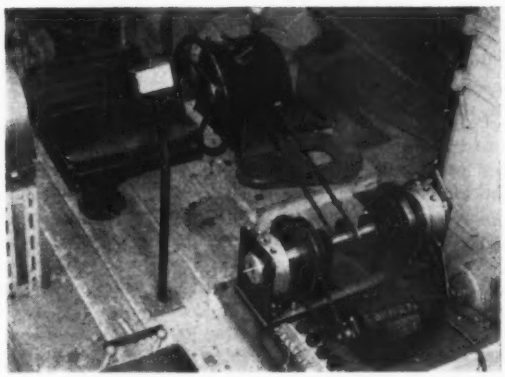


Fig. 15—Input setting unit, ratchet handwheel type

The pushbutton potential divider unit, shown in Fig. 13, has two rows of main pushbuttons marking tens of inches and inches, and a third row of five incremental pushbuttons marking a draft in $\frac{1}{2}$-in. steps from $\frac{1}{2}$ in. to $2\frac{1}{2}$ in. The buttons themselves position motor uniselectors and these operate relays to produce voltages corresponding to the required positions of the servo-operated screwdown motor. This method is superior to the one originally used in which precision resistors were connected as a potential divider directly around the motor uniselector, as it avoids the switching of low voltages which often produces errors in metering circuits of this nature. The scheme is incremental in basic principle and thus differs considerably from the pushbutton scheme proposed for steelworks *R*.

No slab–edge rolling changeover switch is provided on the unit, the operational procedure being to set a given value of screwdown on the main buttons and then to obtain successive values by use of the draft buttons only. When the ingot is tilted and in consequence a large change in screwdown setting is called for, the main pushbuttons must be reset.

This screwdown control scheme starts with an advantage over a contactor-controlled screwdown system in that it is possible to apply continuous control to the motors and thus simple velocity feedback can suffice. This means that a single a.c. tachogenerator can be used for stabilization and an a.c. 50 c/s electronic amplifier used to amplify the error signal.

The feedback unit incorporates the position and velocity feedback units (potential divider and a.c. tachogenerator) and these are mounted on a common plate and driven directly from one of the screwdown motors via a gearbox and sliding pinion arrangement to obviate damage due to end float.

During trials at the works an earlier scheme incorporating a pushbutton input setting unit was used having separate buttons for setting the screwdown for ' slab ' or ' edge ' rolling and a slab–edge change-over switch.

In spite of the screwdown motors being supplied from a 3-field generator, their speed was originally controlled from tappings on the exciter field circuit by means of a master controller, and the original detector consisted of a three-stage two-channel cascade relay amplifier which polarized moving-coil relays and ended with robust relays closing the circuits which were originally closed by means of the master controller. The circuit closely followed that originally used during the trials at steelworks *R*. The velocity feedback unit gave signals proportional to V and $V|V|$. The position feedback unit was coupled via a gearbox to the worm of the screwdown gear. The coupling between the position feedback unit and the worm shaft was a constant source of trouble during the trials which, however, were completed before the sliding coupling idea was adopted. This should prove a complete solution to this problem.

With this early scheme installed, over 100 tons of steel ingots were rolled satisfactorily, and steelworks *A* decided to examine the possibility of equipping their projected new universal mill with position-controlled screwdown motors.

INSTALLATION AT STEELWORKS *J*

The 150-h.p. screwdown motors of the cogging mill at steelworks *J* are shunt wound and Ward-Leonard controlled via a cascade exciter set by means of a master controller.

Requirements

A position control on the screwdown motors was needed which could be set by a handwheel to the initial ' slab ' and ' edge ' values and then inched down by means of a ratchet-lever device, which could be set to give drafts of from $\frac{1}{4}$ in. to 3 in. in $\frac{1}{4}$-in. steps. Memory of the last pass setting on ' slab ' rolling was required whilst rolling ' edge ' and *vice versa*. In addition as much information as possible was required to be displayed to the operator during rolling. The accuracy required was $\pm \frac{1}{8}$ in. in 70 in. of screwdown which is of the order of 1 part in 500. The usual requirements as to speed of screwdown, emergency change back to velocity control, and protection of the drive from running into the end stops were also to be provided.

Proposed analogue–digital scheme for steelworks *J*

The complete scheme finally recommended after trials is shown in Fig. 14. To obtain control of both slab and edge screwdown settings by means of one handle and to incorporate a memory feature as well, it was decided to control two input potential dividers through two alternative magnetic clutches. Either clutch can be driven from a ratchet wheel actuated by means of a hand-set controller handle which turns the ratchet wheel up to 12 teeth at a time, each tooth corresponding to $\frac{1}{4}$ in. of screwdown. A slab–edge rolling switch provides for connection of either potential divider and the one disconnected at the clutch automatically becomes the memory. The whole unit as installed at the steelworks is shown in Fig. 15. The clutches used incorporated no splined shafts to eliminate backlash between the drive and the potential dividers. Power selsyns are also driven by the shafts which rotate the potential dividers and these are used to furnish a display on a special dial, as the orthodox mill screwdown dial was unsuitable for use in remote position control. The new dial unit carries 3 pointers on triple concentric shafts as indicated in Fig. 14. The two input pointers are driven from the two power selsyn links between the input unit and dial unit, and the third pointer is driven from another power selsyn link driven from the motor via a gear box. The effect in operating the mill is that either setting pointer can be moved by the ratchet device and the motor pointer then follows it up and comes to rest behind it. As the setting pointers are yellow and black, and the motor pointer is red, the display is very effective in showing when coincidence has been reached.

In view of efforts in the control industry to standardize industrial 400 c/s electronic amplifiers it was decided to use an amplifier of this type on the installation at steelworks *J*, and the potential dividers in the input setting unit are fed with 50 V at this frequency. An auxiliary circuit at the output end of the pre-amplifier is used to operate a relay chain controlling the brake, and it is possible to use d.c. velocity feedback signals after the rectifier stage in the power amplifier although this is not done at present.[5]

The 400 c/s amplifier is designed to feed out to a metadyne or magnetic amplifier and this in turn controls the field of the main generators of the screwdown drive. The position feedback potential divider is driven directly from the outermost of the three concentric shafts.

The tachometric feedback unit embodies a single a.c. tachogenerator driven through the sliding gear arrangement from the screwdown motors and is similar to that advocated in the installation for steelworks *A*, except that no position feedback unit is incorporated.

CONCLUSIONS

Laboratory tests have shown that remote position control of screwdown drives is a practicable proposition even when the motors are contactor controlled, and it need not be expensive.

A variety of input setting units can be used and these may be either analogue or digital devices or may embody a combination of these.

A d.c. system with polarized-relay error detection offers the simplest system for low-accuracy systems, but for accuracies of the order of 1 part in 500 a.c. electronic amplifiers should be used either at 50 or 400 c/s.

For relay systems or contactor-controlled r.p.c.

systems a double d.c. tachogenerator system is advocated, but for continuous systems a single a.c. tachogenerator is probably more suitable.

Potential-divider error detection, both with a.c. and d.c. supplies, has proved to be satisfactory if high-grade components are employed.

All r.p.c. units installed on the mill require to be sealed against ingress of dust and scale, and this protection should extend to providing glands for all emergent rotating shafts.

Allowance must be made for end float when coupling units axially to the shafts of screwdown motors. Sliding gears and pinions offer a cheap and satisfactory solution. Power relays on contactor-controlled systems should not be installed within earshot of the operator.

In view of the very favourable reception accorded recent installations of r.p.c. in the USA, no new primary mills should be ordered in this country or elsewhere without making full provision for the installation of r.p.c. auxiliaries, even if r.p.c. is not to be installed immediately.

Up to the present insufficient operational test data on BISRA installations has been obtained, but one scheme has already operated successfully (steelworks *A*) and, as a result, the company concerned is exploring the possibility of making a permanent installation. A second scheme has given promising test results on site.

Further attention should be given to the precautions which should be taken to prevent damage to the mill in the event of failure of the control.

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The application of remote position control to forges

SUMMARY OF AN INTERIM REPORT

By L. J. Chant and F. Seredynski

EQUIPMENT is described which has been constructed for the study of remote position control of forging. This has been installed on the BISRA experimental forge in Sheffield, which consists of a conventional 200-ton forging press (Fig. 1) with direct oil drive, and an experimental rail-bound hydraulically driven manipulator (Fig. 2) constructed for the purpose of this research and designed to carry a 6-cwt ingot.

The press is controlled through a solenoid-operated pilot valve. The controlled motions of the manipulator comprise: longitudinal movement of carriage, raising and lowering of the peel, and peel rotation. Hydraulic motors were chosen for the drives on account of their better torque/inertia ratio. A single motor-driven pump with bag-type accumulator supplies all motions and the gripping jaws.

Press controls

Because of the nature of the solenoid-operated hydraulic control valve, essentially an 'on-off' device, the control circuit was made on-off also, that is, the controls have no degree of operation other than the extremes of ' on ' or ' off.' A polarized relay is connected between the sliders of two potential dividers, an input potential divider on the control desk and an output potential divider, chain-driven by the press crosshead. These potential dividers have a common supply voltage and when they are set in similar positions there is no net voltage across the relay and it remains inoperative. Displacement of one or other of the potential dividers causes the relay to operate in the appropriate sense, and its contacts complete the control circuit via further relays to move the press crosshead and restore the original balance condition.

In practice there are two input potential dividers on the control desk, each scaled in inches, one for setting the lower limit of crosshead movement and one for the upper limit. The scale on the upper limit potential divider is, however, marked off in inches of crosshead stroke, and the body of this potential divider is geared to the lower limit setting knob. If the lower limit setting is turned, the upper limit turns in sympathy, the stroke remaining constant at its preset value, but if the upper is turned the stroke length is changed. A relay with changeover contacts selects one or other of these two input potential

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The authors are with the Association's Battersea laboratories.

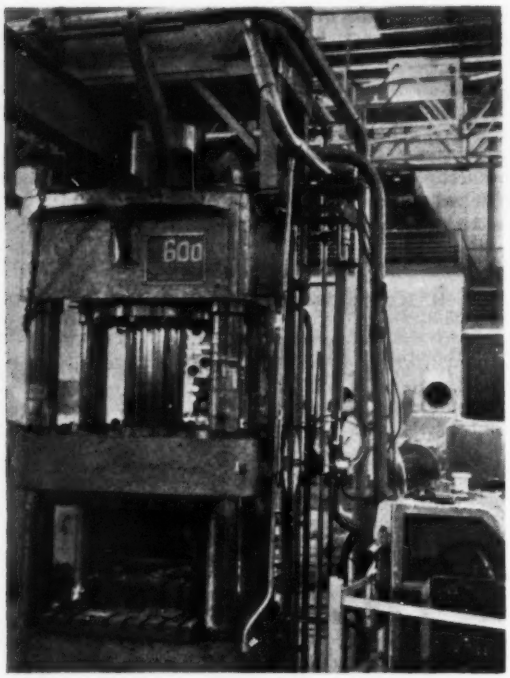


Fig. 1—200-ton forging press

dividers, and the press moves until the output potential divider on the crosshead is in coincidence with the chosen input potential divider. Successive movements of these relay contacts cause the crosshead to reciprocate between the upper and lower limits.

In order to give an anticipatory signal to prevent the crosshead over-shooting the required stopping position, a tachogenerator is coupled to the crosshead movement to give a voltage proportional to the velocity of the crosshead. This voltage (velocity feedback) is added into the polarized-relay circuit in such a manner that it gives the required advanced switching off.

On the downstrokes, when forging, the crosshead has more retardation at the end of its stroke (due to the resistance of the ingot) than it does at the end of the upstroke, and different amounts of velocity feedback are necessary for the two directions. This is achieved by using two preset potential dividers across the tachogenerator and switching from one to the other with additional contacts on the relay which decides the direction of travel of the crosshead.

A multi-position switch enables single stroke, repetitive, or externally timed operation to be used. The consoles for the press and manipulator controls are shown in Fig. 3.

Manipulator controls

The longitudinal movement of the manipulator is derived from a floor-mounted motor and geared by means of a long rack-and-pinion. Like the press it is controlled by solenoid-operated hydraulic valves, and the control system is basically similar to that for the press, with potential dividers to give input and position feedback signals and a tachogenerator driven by the motor for velocity feedback. In this case, however, error detection is by means of electronically operated relays.

Normal forging practice requires progressive withdrawals of the ingot from the press in successive equal or approximately equal amounts. The controls are arranged so that, after pre-selection of the length of each withdrawal (1 in., 2 in., 3 in., or 4 in.), successive operations of a push-button cause successive with-

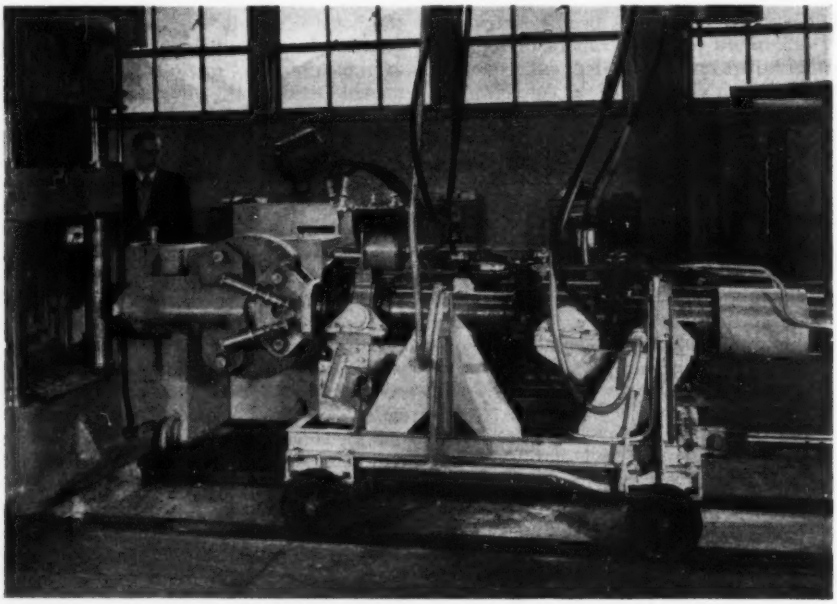


Fig. 2—Forging manipulator

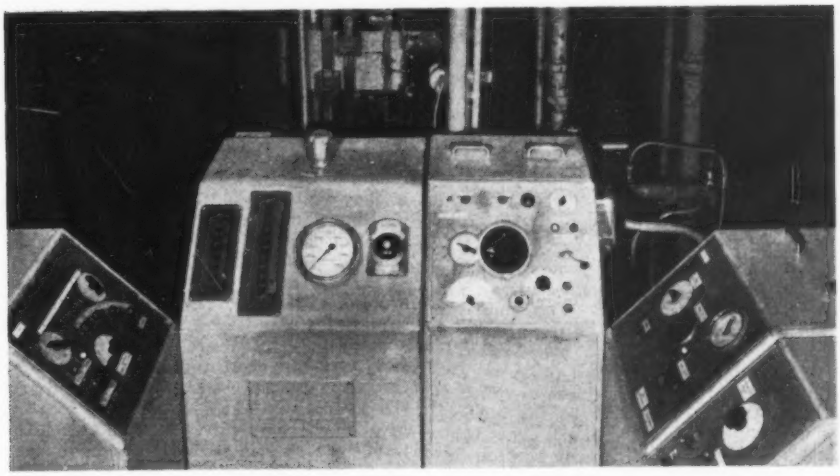


Fig. 3—Control consoles for forging press and manipulator

drawals of the chosen amount. In addition 'tens' and 'units' switches are used to set a position to which, after sufficient withdrawal, the manipulator may be returned by operating a 'reset' button to begin the next pass.

Rotation is provided by a gear-type hydraulic motor mounted on the forward end of the peel. The control system in this case is very similar to that for the longitudinal motion, power to the hydraulic motor being controlled again by solenoid-operated valves. The only real difference lies in the means by which angular position is detected, and here synchros are used instead of potential dividers.

The controls are arranged so that the ingot can be rotated initially to align its faces with the press, and then each successive operation of a push-button rotates the ingot by a predetermined angle. This angle can be 90°, 45°, 22½°, or 15°.

In the vertical motion, the hydraulic cylinder which raises or lowers the ingot incorporates a continuous servo system so that movement of its ram is proportional to movement of its pilot valve, a direct connection between ram and pilot valve providing feedback.

The pilot valve is coupled to an electric motor by nut-and-screw-type gearing and control of this motor is by an on-off electrical system similar to those described. In this case, potential dividers are used for position setting and position detecting, and electronically operated relays control the direction of motion of the electric motor. This in turn moves the pilot valve, and the ram, following up, raises or lowers the ingot.

Automatic sequencing

Press, longitudinal, and rotational controls have been linked by automatic sequencing, the method being to use the relays which control any motion to start the next motion. For example, at the end of a forging down-stroke a relay is operated to begin the up-stroke. Contacts on this relay are arranged in parallel with the starting button of the rotational and longitudinal movements so that each forging stroke causes one step of longitudinal movement and one of rotation, giving a spiral forging pattern. This technique is found useful in planishing round sections.

Automatic cycling

As an alternative to automatic sequencing, cycling can be achieved by the use of a cam-operated switch for starting each of the controlled movements, the cams being driven from a common shaft at a steady speed which can be varied. Each motion is operated once for each complete revolution of the cams, and by adjusting the relative position of the switches the various controls can be actuated at any required times relative to each other. The speed of rotation of the cams dictates the speed at which the sequence of events repeats itself.

Performance

A prototype cycling switch has been built on these lines, but full use has not yet been made of it and a comparison cannot be made between these two sequencing methods.

The aim of the design has been to control the position of the press crosshead to about $\pm \frac{1}{16}$ in., the position of the manipulator carriage to about $\pm \frac{1}{4}$ in., the angular position of the manipulator peel to about $\pm 1°$ and its height to about $\pm \frac{1}{16}$ in. The equipment is still in the course of development, but its performance is already close to this specification, so that one can conclude even now that the application of remote position control to the various motions of a forging press and manipulator is a practical proposition. Although the technique is not in any way new, it is uncommon to find it used in the forging industry. As yet, the savings due to this mechanization of forging have not been measured, but it has been estimated that the time saved could be as much as 25% during a forging operation. Further savings are possible by being able to forge to closer limits, necessitating less subsequent machining. The control achieved is sufficiently promising to justify further work aimed at fully automatic and programmed operation of the forging process.

Discussion on remote position control of screwdown drives and the application of remote position control to forges

This discussion was based on the following papers:

"Remote position control of screwdown drives of primary rolling mills (Interim report)," by *L. N. Bramley, F. Seredynski, L. J. Chant,* and *G. K. Steel.*

"The application of remote position control to forges (Interim report)," by *L. J. Chant* and *F. Seredynski.*

Mr **D. J. Ray** (Steel Company of Wales Ltd.): Since my experience of r.p.c. is limited to screwdown drives of primary rolling mills, I shall confine my general remarks to that application; but I trust that some of them will be relevant to the forging industry. The company with which I am associated has, for the time being at least, decided not to proceed with an installation of r.p.c. on its new universal mill, but full provision has been made for its possible eventual inclusion. This is contrary to the information available to the authors when the paper was being prepared. One of the reasons for this decision is that we are at present preoccupied with large development schemes, and important though the matter under discussion is, we have decided not to take a decision on it for the time being. Personally, however, I am confident that a reliable, well designed and not over-complicated scheme cannot help but improve both quality and production of steel.

Screwdown operation requires considerable concentration on the part of the operator, and, if he could be relieved of at least part of this, the advantages would soon become apparent. I am glad to know that one of the objects of the tests carried out in the preparation of the paper was to produce a system which is comparatively cheap and simple. In my opinion, the essentials of any r.p.c. system applied to screwdown are reliability, accuracy, simplicity, flexibility, and ease of operation from the point of view of the operator. In deciding on a scheme the characteristics of the particular installation must be carefully considered, i.e. the sequence of operation of the screwdown. A simple, flexible, and reliable scheme has often distinct advantages over more complicated schemes which, though they may cater for complete programming with the use of translators, punched cards, etc., nevertheless involve a high standard of maintenance and very often lack sufficient flexibility.

In addition to requiring a considerable amount of concentration on the part of the operators, screwdown operation requires a considerable amount of skill, since parameters such as heat, shape during rolling, and quality have an important bearing on the amount of screwdown required. I would suggest that flexibility is absolutely essential, whatever system is employed. I am aware that certain programming installations are available, which cater for a certain amount of flexibility by fixing only the main points in the programme, such as the tilting operation, but these schemes are unquestionably complicated. The ultimate success of any system will depend on the way in which it is accepted by the operator. I can think of at least two ways in which that acceptance can be destroyed. It may be too complicated in its setting-up procedure to help the operator at all, and he would far prefer to use the ordinary hand controller. It may be said that that is a good reason for installing a programming system; but if parameters, such as heat, necessitated going off programming on a considerable number of occasions, we are defeating the object of giving the operator something which can relieve him of the concentration otherwise required.

My first question to the authors is this: in considering the installation of an r.p.c. system on, say, large slabbing, universal, or similar mills where the number of tilting operations are comparatively few, and nearly all screwdown movements consist of small draft reductions, would it not be better to install what we might call a semi-automatic system, which would merely comprise the requisite number of drafting buttons. Large movements of the screwdown would be left to the hand controller which would by-pass the automatics. These buttons could cover the range of drafting applicable to the mill (say five in $\frac{1}{2}$-in. increments in the case of large slabbing mills) and could be incorporated in the handle of the controller. There are many advantages in this system. From the operator's point of view, this system would, for the period of screwdown operation which consists of small draft increments (this is as high as 90% in a universal mill), simulate complete automatic control since the pressing of the appropriate button on the handle of the controller could in a very short time be done automatically. It would constitute a comparatively simple scheme since no great accuracy as compared to final accuracy would be required. A d.c. system with polarized-relay error detection, as described in the paper, would probably suffice whereas for a completely automatic positioning scheme an additional vernier potentiometer, electronic amplifier, or magslip system would probably be necessary to obtain the accuracy. The final pass requiring considerable accuracy would be made on the hand controller, and thus maximum flexibility would be obtained.

The possibility of overrunning which has generally serious consequences would be considerably less since there would be no long runs on automatic to danger limits.

Finally, the operator would be, as it were, always conversant and kept at maximum efficiency for complete hand operation in the event of breakdown of the r.p.c. system. What are the authors' views on these points?

My second question is a constant topic of discussion where r.p.c. systems are considered, and concerns stand-top equipment. The various analogue and digital schemes referred to in the paper incorporate such stand-top equipment as a re-setting potentiometer, a tacho-generator for velocity feedback, and a velocity squared device. Would not the authors consider it better to put this equipment in, say, the motor room, where the conditions are ideal? An obvious advantage would be that tests and any small observations on this equipment could be done in ideal circumstances, and I am sure that the reliability of the equipment would be far greater. I realize that the stability of the loop might be affected to some small extent during transient conditions, but if the equipment were driven through a power selsyn link with the transmitter coupled to a high-speed take-off point on the mill stand I am sure that the difficulties of instability could be overcome. My experience of the installation at steelworks *A* convinces me that this is essential. I can find fault to a certain extent with some US schemes, but they have realized this important fact. The manufacturers tell us that they are quite sure that the equipment will be reliable on stand top, but I am convinced that this is not so.

Dr **Bramley:** If we do what Mr Ray advocates we shall achieve our immediate object, but I want to proceed along lines which will lead to complete automation of a rolling mill, which is urgently needed. It is a simple device, and it can be 95% automated almost straight away. Mr Ray will realize that r.p.c. is a first step to this end, and a good deal of work must be done after that to get full automation. I agree with him that there must be good flexibility, but the flexibility given by Mr

Jenkins's translator, which will be discussed later is, we consider, adequate for all normal purposes.

I was not sure what Mr Ray meant when he referred to the draft buttons, because we clearly show in the steelworks *A* digital scheme a system in which draft buttons (which were called for by the steelworks) were incorporated. Draft buttons were installed on the mill concerned and were quite successful.

We have done a good deal of work on the moving-coil relay, because we were convinced that it was a very simple device and therefore very desirable; but we came to the conclusion that for servos of an accuracy of better than 1 part in 100 it was no good, and after that we went to a.c. and d.c. electronic schemes. For accuracies of up to 1 part in 100, however, we would still advocate it.

The question of overrunning is important, but we have adequate circuits to look after that. We feel that it needs more attention, but there is no doubt that a proper limit-switch scheme with some safety relays can take care of it. Alternatively, it is possible to use a single potential-divider scheme instead of the double scheme, and then, if there is failure, the whole thing will shut down instead of running into the stops. We have some information on this subject and shall be pleased to discuss it further.

Mr **H. Williams** (Metropolitan-Vickers Electrical Co.): Quite a number of automatic mills have been installed in the UK. One fully automatic mill was installed in Cardiff in 1936, working on limit-switch principles, and there have been quite a number of sheet mills which have incorporated limit-switch-controlled screwdown for many years.

Dr Bramley asks why it is that the steelworks people have not succeeded with r.p.c. before now. I think that the answer to that is the cost. Here I find an anomaly in the paper. It was stated under 'Objects of the investigation,' that "It was considered necessary to take into account the factors of cheapness and simplicity," but in the 'Conclusions,' and in fact throughout the paper, one finds that anything required is described as 'special.' From the Conclusions it will be seen that we have to have analogue or digital devices, and to consider electronic amplifiers and a double d.c. tachogenerator system; all the components have to be high-grade and everything has to be sealed, and so on. All this will increase the cost very considerably.

The cost of an r.p.c. servo-system is very much affected by accuracy and speed of response considerations and so to keep things in perspective the accuracy of a particular system should be quite precisely stated.

As a general comment I would say that to use potential divider units for obtaining the position of reference means that an accuracy not greater than 1 in 250 could be obtained.

With regard to the method of working, I notice that BISRA use a very good tachogenerator system, but we find that the use of a non-linear circuit with velocity feedback achieves the same results in a more elegant way.

I should like to endorse Mr Ray's point about the position of the device on the mill, where it is subject to dirt and dust. This is not the best position, and there is a great deal to be said for locating these things on or near the motors. What steps do the authors propose to take to overcome backlash?

I should also like to know how many operators are used in conjunction with the r.p.c. systems when applied to forges.

Dr **Bramley:** I am directly at variance with Mr Williams on the relative position of r.p.c. in the UK and the USA. There is one company in the USA which alone has successfully installed 62 screwdowns on mills, with another 12 under construction. In the UK we cannot compete with that.

On the question of accuracy, if I aim at a dimension which is $\pm \frac{1}{8}$ in. in 70 in., and suppose (to make it simple) that I aim at 70 in., then, if it is within the accuracy which I require, it will be between 69 $\frac{7}{8}$ in. and 70$\frac{1}{8}$ in., which is 1 part in 560 and not 1 part in 280 as claimed by Mr Williams.

On the question of velocity and $V|V|$ feedback, it is stated in the paper that a great deal of investigation is required on the various kinds of feedback. V and $V|V|$ add up to a log. series, and there is also the possibility of using a square-root feedback. It is a subject which interests us very much, and we propose to investigate it. We are planning to do so at the moment. What we have done already is to make sure, by means of simple velocity plus $V|V|$ feedback, that we have made our system stable, whether it runs from 29 to 30 in. or from 29 to 60 in. With ordinary velocity feedback this will not be achieved in all cases.

We agree that equipment should not be put on the stand top if that can be avoided, but it is not always possible to avoid it. If it goes on the stand top it has to be boxed and all the shafts have to be glanded.

We think that backlash can be controlled. Many of you will be familiar with the work done by Tustin and others before 1947 on divided reset and so on. We are getting ready to carry on this work in the laboratory. We have a 50-h.p. motor with a backlash coupling on it, and this will give us a maximum of about 1% of backlash on 1 000 radians of travel. We can vary this and achieve control with backlash and inertia in the drive, and we are sure that, although we have a backlash of 1%, we are going to achieve better accuracies than that. If we can make the backlash consistent and the friction within the backlash travel consistent we think that we can get reasonable accuracy without extraordinary complication. This work is in its infancy, but the equipment is nearly ready for tests and we hope to do some more work on it shortly.

Mr **Chant:** In reply to Mr Williams's question about the number of men required to operate the forging controls, there are in fact four controlled movements. Of these, one is used infrequently, leaving three to be used much more frequently. With push-button control of each movement one man has to be very nimble-fingered to operate all three together, but with the movements co-ordinated one man can start each pass and then stand back and let the passes proceed.

Mr **F. H. Towler** (Towler Bros. (Patents) Ltd.): My firm have several forging presses being installed with what we call thickness control, which I suppose is vertical positional control, and we are expecting an accuracy of the order of $\pm$ 1 mm. There are installations in France, and others in Germany and in the UK. They are all different, though they come from our own works; some are electric, some hydraulic, and some a combination of the two. We have found that every forgemaster has his own ideas of how he wants the press to be controlled and how the control desk should be arranged. We have persuaded them to have just one control lever, which does not move very much, so that there is very good manual control.

We are now being asked to tie up a manipulator with a forging press. Our problem with the forging press has been comparatively easy, because using a direct oil hydraulic press we have very consistent forging speed. After the forging stroke is finished we come back at constant speed. Our controls, therefore, are comparatively simple. If there are varying speeds of forging or

of approach or return I assume that a 'velocity-squared' feedback becomes essential and will complicate the control, so that there may not be quite the same accuracy; but so far as forging processes are concerned we have found that thickness control is easy.

Now, however, we are being asked to tie it up with the manipulator. The manipulator is much slower than the forging press. I think that the forging press which BISRA have used at Sheffield is comparatively slow; the response is slow; but with a high-speed forging press such as we have developed the problem is that the position control has to move the manipulator fast enough to catch up with the forging press. It is, I think, the manipulator which will ultimately determine the output of the forging press. Many of these manipulators have to move about. They are not on rails, but they are expected to bring the billet from the furnace to the forge, and so on. We must have a number of wires connecting the manipulator with our control desk for the forging press, and we should like to know how many wires there are likely to be, because that is going to be one of our problems. I believe that within the next 12 months we shall see some proof of at least an approach to automatic forging.

Another problem with the manipulator is that there are large inertia effects, and there again I think that we are going to have some difficulties. I wish BISRA all good fortune in the next 12 months, and I feel sure that they will make some progress. They have probably felt a little frustrated up to now, because so many people in the industry want somebody else to do the first experiment or use the prototype. There are several prototypes now in Europe and in the USA, so that those who have lagged behind will soon be wanting to catch up.

Mr **Chant:** We agree that fast manipulation is necessary, but I am not sure that we agree that the manipulator will be the slow part of a manipulator-and-press combination. It is at the moment, with the existing cumbersome types of manipulator, but it is realized that the manipulator must be speeded up, and the one illustrated in our paper is a radical departure in design from the normal types of manipulator with which we have been familiar. Its design is aimed primarily at very fast speed of response, because it is realized that manipulation must take place quickly. If the manipulator is designed with this in mind, we do not see any reason why it should be slower than the press.

Mr **Towler:** What about the wires? How many wires will be needed?

Mr **Chant:** You are talking in terms of a mobile manipulator and, because of this requirement for a light and fast-moving manipulator, one of the design features is to take the power source for the movement off the manipulator and put it on the floor. That cuts down some weight, but makes it no longer mobile. There is no direct answer to your question, because the scheme which we envisage does not have any wires, in your sense, for coping with a mobile manipulator. One could imagine schemes with wires or radio links, but we do not envisage that as the best scheme for getting speedy forging.

Mr **J. A. Stokes** (British Thomson-Houston Co. Ltd.): The current fashion is to have potential dividers for reset. In the early days of r.p.c. they were rejected because their life was unsatisfactory, but I believe that their design has now been improved very considerably. Have the authors done any life tests to find out how the accuracy and linearity vary with life?

Figures 8 and 13 in the paper both refer to steelworks *R*, Fig. 13 being the proposed digital scheme and Fig. 8 the present analogue scheme. The authors state that one of the advantages of the digital scheme is that there is no requirement for a new dial, in that the input setting unit is in the pulpit and that the position feedback potential divider is on the old dial. There seems no reason why the same thing should not have been done on the analogue scheme. The input unit could still have been put in the pulpit. It would require some display in the pulpit, but if it is accepted in one case there is no apparent reason why it should not be in the other.

In Fig. 20, which shows the proposed new scheme for steelworks *J*, it is alarming to find included in the main servo-loop a power selsyn link, which is akin to a long flexible shaft with a flywheel on each end and commonly has a resonating frequency of 1–3 c/s. Such a link must surely have an adverse effect on servo performance.

There is no evident reason why the output potentiometer should not be driven directly from the screwdown drive, leaving the power selsyn link driving the dial only.

It is noted that the servo amplifier is operated from a 400 c/s supply, as opposed to the 50 c/s supply used previously. Since a servo including a power selsyn link could not fully utilize the normal performance of a 50 c/s supply, I would like to know why the authors have used 400 c/s.

The authors mention that d.c. tachos were being dropped in favour of a.c. devices. Have they had difficulties with the d.c. tachos which caused them to take this decision? I ask this because in servomechanisms there is frequently a requirement for integral and differential terms, which are easy to obtain with d.c. tachos, but very difficult with a.c.

I would suggest that when the paper is reprinted the oscillograms should have a time-scale on them to increase their usefulness.

Mr **Chant:** The point about the frequency of the amplifiers was not the frequency response of 400 c/s compared with 50 c/s but that we were interested in using amplifiers of different standard frequencies in order to gain experience in running these frequencies round a steelworks, so that we could say afterwards that we had had experience of each.

Dr **Bramley:** I think we can say that the frequency response problem is not at all onerous at the standard of accuracy to which we are trying to work. Some big manufacturers in the UK will not look at 400 c/s, while others say that 400 c/s is the complete answer. It behoved us, therefore, to examine electronic amplifiers of different frequencies, and we have used one of 50 c/s, one of 400 c/s, and one which had ordinary moving-coil relays in it. The time-scale on the oscillograms in the paper is 0·1 s between lines.

On the question of a.c. and d.c., we agree that tachometric feedbacks are more easily obtained on d.c., but we got tired of our d.c. amplifiers. There is no doubt that the d.c. amplifier is still troublesome. In the end we decided that the thing to do was to use chopper amplifiers but if we could get away with ordinary a.c. tachos we should use a straight a.c. electronic amplifier. We have found that our tachometric feedbacks can be simplified, and we have on one occasion had a contactor-controlled equipment working with straight velocity feedback without any $V|V|$. We are still exploring these possibilities.

We have no quantitative evidence about the potential dividers, but we have had these potential dividers in use for six months on a rolling mill without any visible sign that accuracy is being impaired; but we used very good cam-corrected oil-immersed potential dividers which cost about £36. They were 6 in. dia. and about 3 in. deep, very fine examples, and they seem to last very well.

Mr **H. Fernbach** (The Loewy Engineering Co. Ltd.): It would have been interesting if the authors had drawn a comparison between the problems arising with r.p.c. for mill screwdowns and those arising with r.p.c. for forging presses. Although at a first glance the problems appear the same for both applications there are fundamental differences. Position control for screwdowns resembles other position control on which a wealth of information has been gathered over many years. In this and similar applications the driving mechanism has normally only to effect displacement of the moving part, overcome inertia, and weight, but has not to carry out any deformation work as the ram has in the case of the forging press. Automatic gauge control in the rolling of strip and plate is a special case which both in method and object approaches the requirements of forging presses. Normally the screwdown gear operates at a constant preset speed; acceleration and deceleration are linear. Velocity feedback can be introduced to ensure accurate positioning and to prevent overrun.

Most modern forging presses installed to-date unlike the one described in the paper are powered by air–hydraulic accumulators or weight-loaded accumulators with steam intensifiers. These presses have much heavier moving parts, higher approach, penetration and return speeds than the press described in the paper, and the kinetic energy of the moving parts of modern presses is considerably higher, a factor which aggravates conditions from a control point of view.

Such a press has to carry out the approach stroke where no deformation work is done followed by the actual forging stroke. Whereas during the approach stroke the speed is more or less constant, it will vary considerably during the forging depending on the valve opening, the resistance of the ingot to deformation, and accumulator pressure. The speed characteristic of the forging press can perhaps best be compared with that of a series-wound motor operating on Ward-Leonard control. The amount of valve opening corresponds to the voltage variation and the drop in speed with power applied corresponds to the regulation of the series-wound motor. Such characteristics are not ideal for precision control. Even with a rigidly established forging programme the resistance to deformation is a variable. The press will, therefore, overrun by different amounts if a simple velocity feedback as indicated in the paper is used. Whereas it appears quite feasible to design a satisfactory r.p.c. control for water-powered forging presses, the problem introduces additional requirements which up to now have not been satisfactorily solved.

My second point refers to the use of telephone-type uniselectors which are now employed to carry out vital control functions in screwdown programme control and are apparently envisaged for r.p.c. of presses. When this type of equipment was first proposed for use in steelworks the originators must have encountered a great amount of scepticism as it is so different from anything the steelworks electrical engineer is used to. It now appears to have been proved that in spite of its light construction, it is extremely reliable. Is this, perhaps, an indication that much of the steelworks control equipment is unnecessarily heavy, its construction and shape being based on tradition more than on design from first principles.

With the advent of magnetic and electronic amplifying equipment and contactless switching devices in steelworks, all of which are static devices and are dimensionally relatively small, an examination of contactor gear, where its use is still essential, with a view of radical re-design may be worthwhile.

Can the authors tell us for what type of mill and for what operating speed of screwdown the discontinuous position control obtained by a system of multiple limit switches would be suitable? The company with which I am associated has installed such special devices, with accuracies which are comparable to those mentioned by Dr Bramley, but they are, of course, of a very much simpler nature.

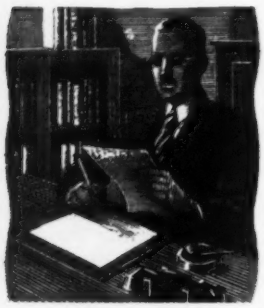
The paper on r.p.c. for forging presses must essentially be regarded as an 'interim' progress report. The company with which I am associated is actively working on the development of r.p.c. in conjunction with others. Co-ordination of press with forging manipulator is one of the many features included in the eventual programme. Any such developments must not call for over-complicated devices and mechanisms but must essentially remain simple in principle and operation.

Mr **Chant:** We have not compared forging and screwdown control, but the techniques are very much the same. I think that the major difference is that whereas with screwdown controls we are confronted with an existing machine which, as was said, may be considered by some to be much larger and heavier than it really need be, in forging controls we have built a special manipulator for the purpose and are confronted with much smaller and more easily moved masses. There is little difference in technique, and that is where the only difference lies between these two avenues of our work.

Concerning the unsuitability of the feedback on forging presses for obtaining adequate anticipation for switching off the system for it to stop at the right place, with a high-speed press we would not use on–off control schemes of the sort outlined here. With continuous hydraulic control, where the press is not merely on or off, but has degrees of speed in between, a continuous position-control scheme would cause the crosshead of the press to slow down progressively and stop at the right place, rather than just shutting it off and hoping that it would coast to the right place, so that the question of the unsuitability of the feedback would not be so apparent.

Dr **Bramley:** There is no reason why the weight should not be reduced and why we should not use post office equipment in certain cases. A good reason for doing so is that it consists of components which have gone through all their teething troubles and been established as reliable pieces of equipment. They do their jobs in a way which cannot be rivalled at the present time by other methods. An example is provided by motor uniselectors, which make it possible to handle 800 pieces of information at a cost of £24. It cannot be done in any other way at that price. The fact is that our control equipment is much too big, and making it smaller is not going to make it weaker. A halfpenny is as strong as a penny. We have to set about it in the right way, but we think that it can be done.

On the question of discontinuous position controls with multi-limit devices, there is one old sheet mill in this country which has a multi-limit switch on it, which operates very efficiently to this day. Its longevity is ascribable, I think, to the fact that it has a first-class multi-limit switch device on it. This mill was put in in the 1920's, and the company which owns it are so pleased with it, that they have recently installed a complete replacement of the r.p.c. feature, which had reached the end of its useful life. I should not like to say that limit-switch schemes should be excluded from future plans, but they are going to take us only a certain distance, and for something big such as a cogging mill we must look further ahead and get the increased flexibility which the ordinary continuous servo-loop will give us.



CORRESPONDENCE ON PAPERS

Correspondence on the paper—

The Mallock cone hardness test and its relation to indentation methods*

By G. H. H. Williams and H. O'Neill

Dr **D. S. Dugdale** (University College of Swansea) wrote: Practical aspects of an interesting method of hardness testing have been described. However, the authors proceed to offer some speculations about the deformation that can only be considered useful if supported by careful reasoning. The Mallock test gives a constant value of hardness by virtue of geometrical similarity of successive configurations as the apex of the cone is compressed. Therefore any explanation of the observed variation of hardness with cone angle should not involve a particular amount of compression, as suggested in the paragraph referring to Fig. 5.

With further reference to the diagrams in Fig. 5, it is stated that a conical plug forms at the top of the specimen and acts as an indenter. This implies that shearing occurs on the surfaces of the annulus surrounding the plug. If deformation occurs in this way, energy is dissipated owing to shearing and to radial expansion of the annulus. It may be instructive to calculate the pressure p which must act on the flat to produce this kind of deformation, assuming a material of shear yield stress k. By considering energy dissipation due to shearing alone, or more simply by considering a frictional stress equal to k acting on the surfaces of the annulus, one obtains the formula

$$p/k = \sec^2 \alpha \operatorname{cosec}^2\beta \cot \beta/(\cot \beta - \tan \alpha)^2$$

where α is the current semi-angle of the Mallock cone and β is the semi-angle of the central plug. Taking the value $\alpha = 33\frac{1}{2}°$, which the authors consider significant, together with the value $\beta = 45°$, a value $p/k = 25$ is obtained. As this value is about six times greater than that which would be expected in practice, the mode of deformation from which it is derived must be regarded as being rather unrealistic.

It is suggested that a transition occurs from one mode of deformation to another. The following argument runs along similar lines to one put forward by the writer for conical indenters.† For Mallock cones of small angle, displaced material flows to the periphery of the cone by a process of localized shearing, the required pressure increasing with cone angle. For cones of larger angle, the applied pressure becomes sufficient to cause subsidence of material over a larger area, as shown by the hardness contours. But the pressure required to bring this about becomes less as the cone angle is further increased. Therefore the transition from one mode of flow to another is marked by a maximum value of hardness. The cone angle at which this occurs would be expected to depend on the shape of the stress/strain curve. It would probably be greater than 67° included angle for cold-worked materials.

The ideal cone angle for a standardized test would be one which facilitated the forming and testing of the conical specimens and which gave a linear correlation between hardness values obtained from this test and from other established tests. These requirements seem to indicate a fairly large cone angle. It is suggested that any new programme of work of this kind might begin with tests involving two-dimensional deformations, and that every effort should be made to utilize recent mathematical work on the plasticity of metals, such as the treatment by Hill‡ of a wedge of plastic-rigid material.

AUTHORS' REPLY

The **authors** replied: We appreciate Dr Dugdale's contribution, and since his formula gave unrealistic results, the complexity of this deformation process was thereby underlined.

One of the objects of the work was to explore conditions for standardization, and Dr Dugdale suggests the use of ' a fairly large cone angle ' for a relationship with established tests. That had been the authors' original view, and until the work had been extended to strain-hardened material it was difficult to reach a conclusion. Mallock cones of 60–90° had given interesting results in relation to ' pressure of fluidity,' and the 90° cone values for Al 1, Armco, steel 22, and steel 93 were only a little lower than the standard Vickers results for these metals. If their 67° Mallock results proved to be somewhat higher, then this angle was preferable to 90°, but on the contrary, copper required a much larger included angle. The authors did not claim to have established a theoretical reason for the 67° feature.

* *JISI*, 1958, vol. 188, pp. 29–37.

† D. S. Dugdale: *J. Mech. Phys. Solids*, 1954, vol. 2, pp. 265–276.

‡ R. Hill: "Mathematical Theory of Plasticity," p. 221: 1950, Oxford, Clarendon Press.

N E W S

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

Recovery of Income Tax under Section 16 of the Finance Act of 1958 by Members and Associate Members of the Institute on their subscriptions

The Commissioners of Inland Revenue have approved The Iron and Steel Institute for the purposes of Section 16 of the Finance Act, 1958. As a result, commencing with the year ending 5th April, 1959, a Member or Associate Member of The Iron and Steel Institute who is assessable to Income Tax under Schedule E in respect of the emoluments of an office or employment is entitled to a deduction from those emoluments of the whole of the annual subscription which is due and payable by him to the Institute in the income tax year—provided that the subscription is defrayed out of the emoluments of the office or employment and that such office or employment is directly relevant to the activities of the Institute.

Any Member or Associate Member of The Iron and Steel Institute who is entitled to the relief should apply to his Income Tax Office as soon as possible for Form P.358 on which to make a claim for adjustment of his "Pay As You Earn" coding.

This concession applies only to those Members and Associate Members of the Institute who are subject to United Kingdom Income Tax regulations, but particulars are being circulated to all Members and Associate Members so that they may all be aware of the concession, should they at any time become subject to United Kingdom Income Tax Regulations.

NEWS OF MEMBERS

New Year Honours 1959

Knight Bachelor
Mr **E. Julian Pode**

C.B.E.
Dr **Maurice Cook**
Mr **T. C. Finlayson**

O.B.E.
Major **P. L. Teed**

Dr **J. L. Aston** has left the Loughborough College of Technology, and is now with the research and development department of Head, Wrightson and Co. Ltd.

Mr **M. D. J. Brisby** has left the Iron and Steel Board to join W. S. Atkins and Partners.

Mr **G. T. Brown** has been awarded the degree of M.Sc. in industrial metallurgy by Birmingham University.

Mr **D. Bruce-Gardner** has been appointed joint managing director of John Lysaght (Scunthorpe) Ltd.

Mr **A. Carr** has been appointed deputy chairman of Thos. W. Ward Ltd.

Mr **P. E. Cavanagh** is now Vice President of Premium Ores Ltd., of Montreal.

Mr. **F. Cousans** has joined the board of Hadfields Ltd.

Mr **L. R. Evans** has been appointed to the board of the English Steel Spring Corporation Ltd., and *not* the English Steel Castings Corporation Ltd., as reported in the December *Journal*.

Mr **F. B. Halford** has obtained a B.Sc. degree in metallurgy.

Mr **D. W. Hubbard** has left the Morgan Crucible Co. Ltd. to join Carblox Ltd.

Dr **R. Hunter** has been appointed a director of the Steel Company of Scotland Ltd.

Mr **A. H. Ingen-Housz** (*Past-President*) has retired from the position of Chairman of the Royal Netherlands Blast Furnaces and Steelworks Ltd.

Mr **M. D. Jackson** has left Hadfields Ltd. to take up an appointment as welding engineer to Yarrow and Co. Ltd., Glasgow.

Mr. **F. N. Lloyd** has succeeded Mr C. E. Lloyd as chairman of N. Hingley and Sons Ltd.

Mr **G. S. T. Martin** has been appointed a director of Smith and McLean Ltd.

Mr **J. R. Menzies-Wilson**, O.B.E. (*Past President*) has retired from the position of managing director of Stewarts and Lloyds Ltd., but remains a member of the board.

Mr **D. O. Pickman** is now with the U.K. Atomic Energy Authority (Industrial Group) at their R. and D. Laboratories, Salwick, near Preston.

Sir **Frederick Scopes** has retired from the position of managing director of Stewarts and Lloyds Ltd., but remains on the board.

Mr **J. L. Steer** has joined The Du Pont Company of Canada (1956) Ltd., at Maitland, Ontario, in the metallurgy and corrosion control section of the Technical Department.

Mr **P. J. Sukolski** has left BISRA to join Mackechnie Brothers Ltd.

Mr **D. F. Walton** has been appointed a director of Thos. W. Ward Ltd.

Mr **H. C. Waterston** has retired from the board of N. Hingley and Sons Ltd.

Mr **G. Wood** has joined the board of Hadfields Ltd.

Dr **Z. Wusatowski** has been appointed Professor at the Polytechnic College, Gliwice, Poland.

Obituary

Mr **Edmund Douglas Bool**, M.I.MECH.E. (*Honorary Member of Council*; *elected* 1948), of Sheffield, on 1st December, 1958.

Mr **John Dunbar**, M.I.MECH.E. (*elected* 1951), of Musselburgh, on 16th December, 1958.

Mr **Frank P. Gilligan** (*elected* 1918), of Hartford, Conn., U.S.A.

Herr **Ernst E. Kugel** (*elected* 1952), of Cologne, Germany, on 29th November, 1958.

Dr **Peter Mackenzie Macnair**, B.SC., A.R.I.C., F.I.M. (*elected* 1924), of Swansea, on 24th November, 1958.

Mr **Robert Thatcher Rolfe**, O.B.E., F.R.I.C., F.I.M. (*elected* 1936), of Bedford, on 9th December, 1958.

IRON AND STEEL ENGINEERS GROUP

Joint meeting in Sheffield

There will be a two-day joint meeting of the Engineers Group and the Sheffield Society of Engineers and Metallurgists in Sheffield on **19th and 20th February.**

The meeting will begin on the afternoon of Thursday, 19th February, with a visit to Shepcote Lane Rolling Mills Ltd., and this will be followed in the evening by the presentation and discussion of a paper on Shepcote Lane by Mr J. R. Edwards.

On the following day there will be a visit to the 11-in. bar mill at the Park Gate Iron and Steel Co. Ltd. in the morning. The afternoon will be devoted to the presentation and discussion of a paper on the water-treatment plant at the Park Gate bar mill by Mr H. C. White (Park Gate Iron and Steel Co. Ltd.) and Mr I. M. E. Aitken (Brian Colquhoun and Partners). The Institution of Water Engineers is participating in the meeting on Friday, 20th February.

Joint meeting in Glasgow

The Engineers Group is holding a joint meeting with the West of Scotland Iron and Steel Institute on **13th March** at 39 Elmbank Crescent, Glasgow. A paper on "The installation and commissioning of an 80-ton electric-arc melting furnace" will be presented by Mr P. M. Thomas, D.S.O., and Mr A. McNaughton. The meeting starts at 6.45 p.m.

Meeting in Holland

The Group is holding a meeting in Holland from **14th** to **17th April.** The programme will include technical sessions, at which a number of papers on ore handling are to be presented and discussed, and works visits to the IJmuiden plant of the Royal Netherlands Blast Furnaces and Steelworks Ltd., to ore-handling installations in the neighbourhood of Rotterdam, and to the Rotterdam Drydock Company. Notices and application forms will be circulated to members later this month.

AFFILIATED LOCAL SOCIETIES

East Midlands Metallurgical Society

Owing to his absence abroad, Major P. L. Teed was unable to deliver his lecture on "Titanium—a broad survey" to the Society on 6th November, as originally announced. He will be giving it instead on 3rd February at the Electricity Lecture Theatre, Carrington Street, Nottingham, at 7.30 p.m.

POWDER METALLURGY JOINT GROUP

Postponement of Meeting

The meeting of the Group arranged for 12th March has been postponed until Wednesday, **29th April,** at 9.30 a.m. at Church House, Westminster. The theme for discussion will be "Theoretical aspects of sintering". On the evening of that day there will be a conversazione at 17 Belgrave Square, London S.W.1, for which tickets are required.

EDUCATION

Course on cupolas

The Department of Industrial Metallurgy at Birmingham University is arranging a series of lectures dealing with theories, current practices, and developments in the most important aspects of cupola work. The fee for the course, which will be held on 23rd–25th March, is two guineas; further information and application forms may be obtained from the Department, The University, Edgbaston, Birmingham 15.

CIBA Fellowship Trust

The CIBA group of companies has recently established a Fellowship Trust, for the purpose of improving and increasing the interchange of ideas between scientists in the UK and on the Continent.

A number of fellowships will be awarded for tenure during the academic year 1959–1960 at Continental universities or institutions for research in chemistry, physics, or some allied scientific subject. They are available for graduates of universities in the UK or Eire, both those graduating this year and those who have already obtained their Ph.D. or who have been working industry.

Further details may be obtained from the Secretary, CIBA Fellowship Trust, CIBA (A.R.L.) Ltd., Duxford, Cambridge.

New higher technological award

The National Council for Technological Awards announced recently that in order to encourage qualified men and women to undertake further study beyond the level of the Diploma in Technology and carry out original investigations, they have decided to create an award higher than the Diploma in Technology. Their intention is that this award shall be a mark of outstanding distinction granted to a student who has proved his ability by completing a substantial programme of work demanding the application of his knowledge to the solution of a problem of value to industry.

The Council will establish a college of technologists, to be known as "The College of Technologists," and the new award will take the form of Membership of this College (M.C.T.).

To qualify for this new award a student must undertake a programme of work to be carried out jointly in industry and at a technical college. This programme may be concerned with any technological aspect of industrial activity, such as research, development, design, production, or market investigation. To carry out successfully post-diploma work of this character, students must remain in contact with industry or with commercial laboratories. The new award is designed to avoid the need for removing a technologist from contact with industry for a considerable period of time immediately after he has gained the Diploma in Technology or an equivalent first qualification.

Students must apply to The College of Technologists, through the technical college at which they will study, for registration as candidates. The College will consider particularly the qualifications and experience of the student, the suitability of the programme offered, and the arrangements to be made for carrying out the work both at the technical college and in industry. The programme offered should be related to the student's personal experience in industry and must have the approval of his employer. Its nature must be such that it is likely to result in a useful contribution to technological knowledge and that, like the Council's first award, it requires industrial experience and academic study extending over a substantial period. A three-year period of work would cover the Council's requirements, so long as a high proportion of a student's time is devoted to the programme of work proposed. The Council hope that employers will readily see the advantage of sponsoring such investigations and give students time for them.

Registration of candidates will not be restricted to holders of a Diploma in Technology, but may be extended to holders of equivalent qualifications. Teachers in technical colleges will be encouraged to become candidates for the award.

BRITISH NUCLEAR ENERGY CONFERENCE

Convention on thermonuclear processes

In conjunction with the British Nuclear Energy Conference, the Institution of Electrical Engineers is holding a convention on thermonuclear processes on 29th and 30th April at the offices of the Institution, Savoy Place, London, W.C.2. The proceedings will be opened by Sir John Cockcroft, O.M., and will consist of a series of papers and discussions on the basic physics of thermonuclear processes, the prototype British experiments, constructional features of Zeta I, design problems in future Zeta installations, and the possibilities of direct conversion from nuclear to electrical energy.

Further details may be obtained from the Secretary, Institution of Electrical Engineers, Savoy Place, London, W.C.2.

FORTHCOMING CONFERENCES

Aspects of magnetism

The Institute of Physics is holding a conference on "Some aspects of magnetism" in Sheffield from 22nd to 24th September. The subjects to be covered are:

(i) Fundamental theories of ferro-, ferri-, and antiferromagnetism, including magnetic structure.
(ii) Theories of technical magnetization processes, including hysteresis, coercivity, anisotropy, and directional effects.
(iii) Theoretical and experimental studies of domain phenomena in bulk materials and thin films.
(iv) Experimental and theoretical studies of antiferromagnetism in metals and non-metals.

Full details are available from the Secretary, Institute of Physics, 47 Belgrave Square, London, S.W.1.

Co-ordination chemistry

Under the sponsorship of the International Union of Pure and Applied Chemistry (IUPAC), the Chemical Society is organizing an international conference on co-ordination chemistry, to be held in London from 6th to 11th April. Details may be obtained from the Secretary, The Chemical Society, Burlington House, London, W.1.

International Foundry Congress

Madrid will be the setting for the 26th International Foundry Congress, which is to be held from 4th to 10th October. The Instituto del Hierro y del Acero will be the hosts on this occasion. There will be a full programme of meetings, works visits, and social functions in Madrid, to be followed by post-congress tours in northern and southern Spain. Enquiries should be sent to the Instituto del Hierro y del Acero, Villanueva 13, Madrid, Spain.

Symposium on inhaled particles and vapours

The British Occupational Hygiene Society is to hold an international symposium on inhaled particles and vapours at Oxford in April, 1960. Contributions are invited; those wishing to contribute are invited to communicate with Mr W. H. Walton, Mining Research Establishment, National Coal Board, Worton Hall, Worton Road, Isleworth, Middlesex.

NEWS OF SCIENCE AND INDUSTRY

Iron and Steel Board change

Sir Cyril Musgrave, Permanent Secretary to the Ministry of Supply, is to succeed Sir Archibald Forbes as chairman of the Iron and Steel Board on 1st March.

BISF presidency

Mr Lewis Chapman, C.B.E. (chairman, William Jessop and Sons Ltd.) succeeded Sir Andrew McCance, F.R.S. (chairman and managing director, Colvilles Ltd.) as president of the British Iron and Steel Federation on 1st January. Mr. R. F. Summers (chairman, John Summers and Sons Ltd.) has been appointed president-elect for 1959.

Translations of Russian technical journals

Arrangements have recently been made for the publication of complete English translations of two important Russian technical journals.

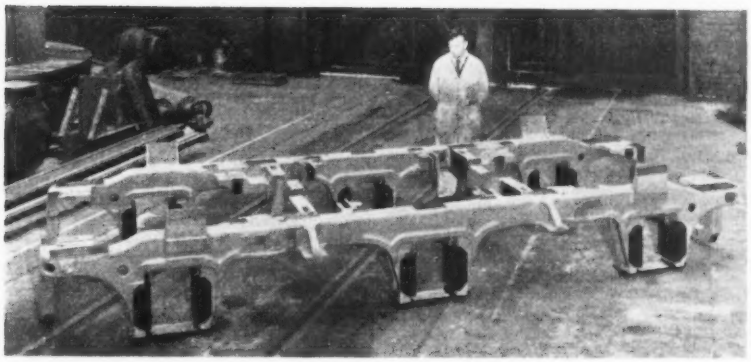
The British Welding Research Association is undertaking the production of "Automatic Welding" (*Avtomaticheskaya Svarka*), a monthly journal published by the Arc Welding Institute of the Order of the Red Banner of Labour at Kiev. The August 1958 issue has been translated as a specimen, and is available on loan from BWRA, 29 Park Crescent, London, W.1; the subscription price for the 12 issues of 1959 will be ten guineas.

The leading Russian journal on production techniques and operation, *Stanki i Instrument*, is being translated by the Production Engineering Research Association, and will be published monthly under the title "Machines and Tooling," starting with the January 1959 issue. Annual subscription rates are as follows:

Ordinary rate within UK	£3 10*s.* 0*d.*
„ „ outside UK	£4 4*s.* 0*d.*
For approved non-profitmaking organizations within UK	£2 9*s.* 0*d.*
For approved non-profitmaking organizations outside UK	£3 2*s.* 0*d.*
Single copies within UK	7*s.* 0*d.*
„ „ outside UK	7*s.* 6*d.*

Orders and enquiries should be sent to The Secretary, PERA, Melton Mowbray, Leicestershire.

The Iron and Steel Institute has been invited by DSIR to undertake the translation of *Stal*, the well known Russian iron and steelmaking monthly. Full details will be announced shortly.



DSIR 5-year plan

Expenditure on research by the Department of Scientific and Industrial Research will be nearly doubled in the next five years. About £61 million will be available during the period 1959–1964. Expansion will continue steadily throughout the period, and for the year 1963–1964 expenditure is planned to reach £14 million.

The largest expansion will be in the field of scientific grants to universities; post-graduate awards to students will increase, so that by 1963–1964 some 3 800 students will be aided by DSIR. Research in the Department's own laboratories will require an increase of staff at a rate of about 6% annually, and grants to research associations will also be raised.

This information was given in the House of Commons recently by the Parliamentary Secretary to the Ministry of Works.

Vacuum furnace alliance

The General Electric Co. Ltd. and Vacuum Industrial Applications Ltd. have reached an agreement to combine the resources of the two companies in the vacuum-heating field for the development of new techniques and the design and manufacture of complete vacuum-furnace installations. All enquiries are to be handled by General Electric.

Brussels award for British Timken

The exhibit of British Timken Ltd. at the Universal and International Exhibition 1958 at Brussels has been awarded the Grand Prix for Precision Mechanics by the unanimous vote of an international panel of judges. The stand was designed by Mr Leslie Dorricott, Manager of British Timken's Publicity Department.

Mill-drive contract for AEI

Associated Electrical Industries Ltd., Heavy Plant Division, has been awarded a contract for the supply of the electrical main-drive equipment for a new 12-ft twin-motor reversing plate-roughing mill, to be installed at the Appleby Steelworks of the Appleby-Frodingham Steel Company.

Diploma for English Steel

A Diploma of Honour has been awarded by the International Jury of the Brussels World Exhibition to the English Steel Castings Corporation Ltd. for the *Commonwealth* one-piece cast-steel bogie (*see above*) exhibited in the British Industries Pavilion at the Exhibition.

BCIRA changes

Dr J. G. Pearce, C.B.E., has retired from the position of Director of the British Cast Iron Research Association. He has been succeeded by Mr H. Morrogh, formerly Deputy Director; Dr H. T. Angus, hitherto Assistant Director, is now Deputy Director.

It was in 1924, three years after the Association was founded, that Dr Pearce became Director; previously he had been associated with Sir Arthur Fleming in the planning and organization of the research and education department created by the Metropolitan-Vickers Electrical Co. Ltd., in Manchester. He is a graduate of Birmingham University, and holds an honorary doctorate from Aachen University. He received the O.B.E. in 1950 and the C.B.E. in 1957. Dr Pearce has served on many national and international committees, and has always had a special interest in education; he is Vice-Chairman of the Board of Governors of the National Foundry College, Wolverhampton.

Mr Morrogh joined BCIRA in 1934 as a member of the staff of the Metallography Department. In 1942 he became Senior Research Officer, and he was promoted to Research Manager in 1946, becoming Deputy Director in 1957. He received an Andrew Carnegie Scholarship in 1940 and was awarded a Carnegie Gold Medal in 1946; he was further honoured by The Iron and Steel Institute ten years later when he became Sir Robert Hadfield Medallist. Dr H. T. Angus is a graduate of Leeds University; he was Chief Chemist and Metallurgist at the Parkinson Stove Co. Ltd. for 18 years before joining BCIRA.

Science on show

Science in all its aspects is to be the subject of an exhibition to be staged at Olympia, London, in October. The International Scientific Research Exhibition is being organized to illustrate the story of scientific achievement, to demonstrate the influence of scientific development on everyday life, and to explain the promise scientific discovery and research holds for the future. Four main themes have been chosen—health and food, materials, transport and communications, and power and industry. Exhibits from all over the world, and embracing university, government, and industrial scientific research will be on display.

Industrial Publications Received

Information sheet no. M840 from William Jessop and Sons Ltd. is devoted to zirconium.

Hilger and Watts Ltd. have produced a booklet (CH 405/2) on direct-reading spectrographs.

Brixil 77, a briquette containing silicon and other active chemicals for increasing cupola efficiency, is the subject of leaflet C.I.A. from Foundry Services Ltd.

Armoured heaters for preheating and stress-relieving of welds and other forms of heat-treatment are described in a brochure from Electrothermal Engineering Ltd.

Publication no. 1700 from Johnson, Matthey and Co. Ltd. deals with platinum laboratory apparatus.

Filtration for oil-burning equipment is the subject of a brochure from Auto-Klean Strainers Ltd.

"Incanite: the special process cast iron" is the subject of leaflet no. V.11C from The Incandescent Heat Co. Ltd.

Catalogues E–CF21 and E–CF33 from Fireye Controls Co. Ltd. describe a new form of flame-failure safeguard and programmer controller for pressure-type gun burners burning light oil.

The Head Wrightson Machine Co. Ltd. has produced a leaflet on draw benches for tubes.

Change of Address

The City and Guilds of London Institute has moved to its new headquarters at 76 Langham Place, London, W.1 (LANgham 3050).

Corrigenda

The following translation errors have been pointed out in the paper by Professor A. N. Pochwisnew on "New Methods of Pig-iron Manufacture" (*J.I.S.I.*, 1958, Nov., vol. 190, pp. 337–338):

1. p. 337, Fourth line of final paragraph, and footnote, authority quoted is Russian engineer *Esmansky*, and not Asmansky.
2. p. 338, Second line below equation should read "in accordance with the standard *and high-pressure* conditions for blast-furnace operation."
3. Twelfth line below equation, blast temperature should be *1000°C*, not 100° C.
4. Section headed "Size of Furnaces and Constructional Features," dimension (iii) is *taphole diameter*, not shaft diameter.

The following errors in the information given in the paper by F. J. Clark and J. L. Harrison on "Tonnage Oxygen" (*JISI*, 1957, vol. 186, pp. 305–323) have been pointed out by the authors:

1. Table Vc, cols. 2 and 3: 12·0 and 11·25 instead of 9·5 and 8·25 respectively.
2. Tables VI*a*, VI*b*, and VI*c*, col. 2: "lime price" should be £4 4*s*. 0*d*.
3. Table VI*b*, col. 4: "Ore and scale" should be 0·11.
4. Table VI*c*, col. 3: "Ore and scale" should be 0·12.
5. Table VII*d*, col. 3: "Gross cost" should be £18 5*s*. 0*d*.

In the paper by H. C. Child and G. T. Harris on "Vacuum-melting of steels" (*JISI*, 1958, Dec., vol. 190, pp. 414–431), the molybdenum contents were omitted from the analyses given on p. 424. They are as follows:

	Nimonic 100	W.1312	W.1399
Mo, %	4·5–5·5	4·5	6

Also, in the third paragraph of the right-hand column of p. 424, there are two references to Table XII; these should have been to Table XI.

DIARY

2nd Feb.—Cleveland Institution of Engineers—"*The design and construction of steam generators for nuclear power stations*," by F. Carr—Cleveland Scientific and Technical Institution, Middlesbrough, 6.30 p.m.

3rd Feb.—East Midlands Metallurgical Society—"Titanium—a broad survey," by P. L. Teed—Electricity Lecture Theatre, Carrington Street, Nottingham, 7.30 p.m.

3rd Feb.—Sheffield Metallurgical Association—"*The production of heavy castings*," by J. H. Pearce—BISRA, Hoyle Street, Sheffield, 7 p.m.

4th Feb.—Institute of Fuel (British Nuclear Energy Conference)—"*A radioactive corrosion probe*," by G. Anson—

Institution of Civil Engineers, Great George Street, London S.W.1, 5.30 p.m.

4th Feb.—MANCHESTER METALLURGICAL SOCIETY—"*Micro-mechanism of fracture*," by Professor W. S. Owen—Central Library, Manchester, 6.30 p.m.

4th–7th Feb.—NATIONAL METALLURGICAL LABORATORY—Symposium on the iron and steel industry in India—Jamshedpur, India.

6th Feb.—STAFFORDSHIRE IRON AND STEEL INSTITUTE — Annual Dinner — Wulfrun Hall, Wolverhampton.

7th Feb.—SWANSEA AND DISTRICT METALLURGICAL SOCIETY—"*Recent developments in cast iron*," by I. C. H. Hughes—Central Library, Swansea, 6.30 p.m.

9th Feb.—LINCOLNSHIRE IRON AND STEEL INSTITUTE—Film show—North Lindsey Technical College, Scunthorpe, 7.30 p.m.

10th Feb.—SHEFFIELD METALLURGICAL ASSOCIATION (Refractories Group)—"*Refractories and the oxygen steelmaking process*," by J. L. Harrison and D. W. N. Pitts—BISRA, Hoyle Street, Sheffield, 7 p.m.

11th Feb.—NORTH WALES METALLURGICAL SOCIETY—"*Some applications of X-ray diffraction in metallurgy*," by Professor H. Lipson, F.R.S.—Flintshire Technical College, Connah's Quay, 7 p.m.

11th Feb.—SOCIETY OF CHEMICAL INDUSTRY (Corrosion Group)—"*Recent research on the corrosion of tinplate*," by S. C. Britton and K. Bright—14 Belgrave Square, London S.W.1, 6.30 p.m.

12th Feb.—EBBW VALE METALLURGICAL SOCIETY and THE IRON AND STEEL INSTITUTE (Engineers Group)—"*Some engineering features of the new oxygen/steam blowing installation at the Ebbw Vale basic Bessemer plant*," by H. F. Padbury—RTB Lecture Rooms, 7.15 p.m.

12th Feb.—LEEDS METALLURGICAL SOCIETY—"*Operational research in the steel industry*," by G. D. Jordan—Chemistry Wing, University of Leeds, 7.15 p.m.

12th Feb.—LIVERPOOL METALLURGICAL SOCIETY (Joint Meeting with The Iron and Steel Institute)—"*The Russian steel industry*," by R. Wilcock—Department of Metallurgy, University of Liverpool, 7 p.m.

12th Feb.—NEWPORT AND DISTRICT METALLURGICAL SOCIETY—Industrial films—Whitehead Institute, Newport, 7 p.m.

13th Feb.—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—"*Operational research with particular reference to open-hearth charging*," by R. H. Collcutt—39 Elmbank Crescent, Glasgow, 6.45 p.m.

16th Feb.—SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—"*Automatic press forging*," by J. G. Wistreich and J. D. Stringer—Sheffield University, 7.30 p.m.

17th Feb.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Why are steelmaking reactions so slow?*" by Dr R. G. Ward—BISRA, Hoyle Street, Sheffield, 7 p.m.

18th Feb.—MANCHESTER METALLURGICAL SOCIETY—"*High-temperature alloys*," by D. R. Wood—Central Library, Manchester, 6.30 p.m.

19th Feb.—NORTH-EAST METALLURGICAL SOCIETY—"*Metallurgical education*," by Professor G. V. Raynor—Cleveland Scientific and Technical Institution, Middlesbrough, 7.15 p.m.

19th Feb.—STAFFORDSHIRE IRON AND STEEL INSTITUTE—Symposium on the non-destructive testing of steel—Station Hotel, Dudley, 7.30 p.m.

19th Feb.—IRON AND STEEL ENGINEERS GROUP and SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—Joint meeting—Sheffield.

20th Feb.—INSTITUTION OF WATER ENGINEERS, IRON AND STEEL ENGINEERS GROUP, and SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—Joint meeting—Sheffield.

25th Feb.—SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—"*The mechanical marshalling of railway wagons in works sidings*," by G. W. Grossmith—Sheffield University, 7.30 p.m.

2nd Mar.—CLEVELAND INSTITUTION OF ENGINEERS—"*Biological treatment of effluent*," by J. W. Abson and K. H. Todhunter—Cleveland Scientific and Technical Institution, Middlesbrough, 6.30 p.m.

3rd Mar.—SHEFFIELD METALLURGICAL ASSOCIATION—"*The competitive position of the British steel industry*," by E. T. Sara—BISRA, Hoyle Street, Sheffield, 7 p.m.

4th Mar.—MANCHESTER METALLURGICAL SOCIETY—"*The behaviour of steels during hot working, with particular reference to hot extrusion processes*," by P. Sukolski—Central Library, Manchester, 6.30 p.m.

4th Mar.—SOCIETY OF CHEMICAL INDUSTRY (Corrosion Group)—"*The diagnosis of the causes of corrosion failures*," by J. B. Cotton, R. A. Hine, E. E. White, and K. A. Chandler—14 Belgrave Square, London S.W.1, 6.30 p.m.

5th Mar.—EAST MIDLANDS METALLURGICAL SOCIETY—"*Plastic-coated steel sheet*," by F. H. Smith and W. E. Martin—College of Art, Green Lane, Derby, 7.30 p.m.

5th Mar.—LEEDS METALLURGICAL SOCIETY—"*Metallurgical applications of high-resolution microscopy*," by Dr J. Nutting—Chemistry Wing, University of Leeds, 7.15 p.m.

7th Mar.—LIVERPOOL METALLURGICAL SOCIETY—Sixth annual conversazione—Department of Metallurgy, University of Liverpool, 7 p.m.

9th Mar.—LINCOLNSHIRE IRON AND STEEL INSTITUTE—Annual General Meeting—followed by young members' papers—North Lindsey Technical College, Scunthorpe, 7 p.m.

9th Mar.—NORTH-EAST METALLURGICAL SOCIETY—"*Development of the tungsten filament lamp*," by Dr B. P. Dudding, M.B.E.—Cleveland Scientific and Technical Institution, Middlesbrough, 7.15 p.m.

10th Mar.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Impact transition temperatures*," by Dr B. Cina—BISRA, Hoyle Street, Sheffield, 7 p.m.

BRITISH IRON AND STEEL INDUSTRY TRANSLATION SERVICE

The following translations are now available, in addition to those given on p. 84 of the January, 1959, issue of the Journal:

888. RÄDEKER, W., and M. WILD: "The Removal of Scale from Steel Plates." *Stahl u. Eisen*, 1958, Jan. 23rd, pp. 100–103. (£3)

916. BOUTONNET, P., *et al.*: "Basic Bessemer Steel Blown with a Mixture of Oxygen and Carbon Dioxide." *Rev. Mét.*, 1956: Introduction and Part I: 'Production of Steel with Low Nitrogen Content,' Aug., pp. 575–583. (£4 10*s.* 0*d.*). Part II: 'Laboratory Tests: Analysis and Mechanical Properties of Different Types of Steel,' Aug., pp. 584–618. (£8 10*s.* 0*d.*). Part III: 'Results of Tests on an Industrial Scale: Drawn Hot and Cold Rolled Thin Sheet, Cold-rolled Strip' (with discussion), Sept., pp. 665–681. (£3)

1082. ČIHAL, V., and J. JEŽEK: "The Morphology of Precipitates in Titanium Stabilized Steels." *Hutnické Listy*, 1956, March, pp. 151–154. (£4 10*s.* 0*d.*)

1086. HARJES, W.: "Resistance to Thermal Shock of Various Basic Refractories." *Radex Rundschau*, 1957, (2), pp. 501–507. (£3 10*s.* 0*d.*)

1088. ARTYUKH, V. S.: "Comparison of Pneumatic and Hydraulic Braking Devices for Pilger Mill Feed Mechanisms." *Stal'*—Rolling and Tube Manufacture Supplement, 1958, pp. 338–351. (£4 15*s.* 0*d.*)

1091. ANON.: "Complex Automatic Control in the Iron and Steel Industry." *Stal'*, 1958, June, pp. 481–485. (£5)

1093. HOFF, H., and G. FISCHER: "Observations on the Bauschinger Effect on Mild and Medium-hard Steels." *Stahl u. Eisen*, 1958, Sept. 18th, pp. 1313–1320. (£5 15*s.* 0*d.*)

1101–1103. *Papers from 'Production of High-strength Cast Iron,' ed. L. I. Fantalov, Moscow, Akad. Nauk S.S.S.R.*, 1955.

1101. BESHLYK, A. S.: "Experience in the Casting of Rolling Mill Rolls in Cast Iron Modified with Magnesium," pp. 173–181. (£5)

1102. KLETSKIN, G. I., and L. YA. OZERINA: "Experience in the Development and Adoption of a Production Technique for Cast-iron Modified with Magnesium," pp. 182–191. (£5 5*s.* 0*d.*)

1103. PETROV, I. P.: "The Development and Adoption of a Technique for Casting High-strength Iron." (Experience at the Syzran Hydroturbine Works) pp. 192–199. (£4 10*s.* 0*d.*)

1105. MYSLIVEC, T., and S. HOŇEJŠ: "Flaws and Defects in Railway Tyres and Some Possible Methods of Their Prevention." *Hutnické Listy*, 1956, Jan., pp. 1–9. (£7 15*s.* 0*d.*)

1106. DECKER, A., and L. BOUSMANNE: "Contribution to the Study of Blast Furnace Gas Composition. Application to the Calculation of Coke Consumption." *Rev. Univ. Mines*, 1958, March, pp. 80–105. (£9 10*s.* 0*d.*)

1108. HANSEL, F.-E.: "Ergonomic Design of Driver's Cab and Control Apparatus in Cranes." *Stahl u. Eisen*, 1958, Sept. 18th, pp. 1326–1332. (£5)

1112. MURATA, I., *et al.*: "Open-hearth Furnace Operation with Cold Coke-oven Gas under High Pressure." *Tetsu-to-Hagané*, 1957, Jan., pp. 17–23. (£10)

1113. TUMAREV, A. S., and L. A. PANYUSHIN: "Reduction of Iron Oxides in a Layer at High-gas-phase Pressure." *Stal'*, 1958, Sept., pp. 769–776. (£6)

1117. FEIGIN, G. D.: "Comments on L. L' Zusman's Paper 'Economic Efficiency of Rolling Light Sections'." *Stal'*, 1958, July, pp. 652–653. (£1 10*s.* 0*d.*)

1127. HASIMOTO, H. A.: "Aerodynamic Design of the Open-hearth Furnace." VIII—'Conclusions.' *Tetsu-to-Hagané*, 1957, Nov., pp. 1194–1199. (£6 15*s.* 0*d.*)

1128. SCHÖFFMAN, E., and H. MALISSA: "The Determination of Small Titanium Contents in Iron Alloys and Ores after Separation of the Heavy Metals with Pyrrolidine Dithiocarbamate." *Arch. Eisenhuttenwesen*, 1957, Oct., pp. 623–624. (£2 15*s.* 0*d.*)

1137. POCHWISNEW, A. N.: "The Metallurgical Evaluation of Iron Ores and Other Raw Materials." *Metallurgie u. Giesserei-Technik*, 1955, Mar., pp. 82–85. (£2)

1150. MÜLLER, E. A.: "The Use of Reflecting Substances in Heat Protection." *Verhandl. Deut. Ges. f. Arbeitsschutz*, 1958, vol. 5, p. 158. (£2 5*s.* 0*d.*)

1151. KÖLBEL, H.: "The Possibilities of the Utilization of Carbon Monoxide-containing Gases for the Synthesis of Hydrocarbons." Summary. *Chemie-Ingenieur-Technik*, 1957, vol. 29, p. 505. (£1 10*s.* 0*d.*)

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

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* Abstracts, the reference to which is marked with an asterisk are to be made available as translations.

MINERAL RESOURCES

The Mineralogy and Conditions of Formation of the Dark Green Iron Ores of Kerch. I. A. Shamrai and V. I. Sorochinskaya. (*Doklady A.N.*, 1958, **120**, (4), 875–878).

Iron Ore Resources of New Zealand. J. Luke. (*N.Z. Dept. Sci. Ind. Res., Inf. series, Bull.* 6, 1955, pp. 28).

ORES—MINING AND TREATMENT

The Future of the Supply of Iron Ore to the Belgian Iron and Steel Industry. (*Echo Mines*, 1958, May, 287–288). Demand and sources are reviewed.

Iron Ore in Canada. A. Hopkins. (*Mine quarry Eng.*, 1958, Oct., 459–464). Canadian markets and companies engaged in ore production are surveyed.

Pneumoconiosis Prevention and Dust Control in Ore Mining II. H.-E. Bröcker. (*Neue Hütte*, 1958, **3**, May, 272–280). Dust control during shot-firing, dust suppression by spraying during ore mining and transport, dedusters, and the salt treatment for finding deposited dust, are all discussed.—L. J. L.

Progress in Developing Fire-Resistant Hydraulic Fluids. S. P. Polack. (*Iron Steel Eng.*, 1958, **35**, Aug., 87–92). A programme of research planned and being carried out by the Bureau of Mines is described, with the object of producing a non-inflammable hydraulic oil for use in mining machinery.

Mining of Minnesota Ores and their Preparation for Smelting. S. M. Meleshkin. (*Stal'*, 1958, (7), 593–598).

Factors Affecting the Choice of a Technique for the Treatment of Crushed and Agglomerated Lorraine Ore. C. G. Thibaut. (*Centre Doc. Sidér. Circ.*, 1958, (4), 803–806). Energy and gas balances for blast furnace operation on Lorraine iron ores are considered for a wide degree of burden preparation from zero to 100% self-fluxing sinter. The energy requirements for the burden preparation are also considered.—B. G. B.

X-Ray Study of a Magnetite Ore. S. Z. Ali. (*J. Sci. Ind. Res.*, 1958, **17B**, July, 241–247). A rich ore from Daltonganj (Bihar) contained ~ 30% more Fe_2O_3 than expected from the FeO content. This appeared to be due to entrainment of haematite particles in the magnetite passing from a magnetic separator.

The Reduction of Higher Iron Oxides by Graphite and Charcoal with Additions of Na_2CO_3 and K_2CO_3. S. S. Lisnyak, E. P. Tatievskaya and G. I. Chufarov. (*Doklady A. N.*, 1957, **116**, (4), 656–659). Experiments on the reduction of Fe_2O_3 and Fe_3O_4 were carried out at temperatures of 700° to 1180° C in a vacuum and with the removal of gaseous products. The results obtained are given in the form of curves on three diagrams: velocity of reaction plotted against degree of reduction. The effects of alkali carbonate addition, the rate of reduction, the composition of gases and other features are discussed in detail—S. I. T.

Electrothermic Reduction of Sardinian Iron Ores. G. Zuliani. (*Met. Ital.*, 1958, **50**, July, 273–279). [In Italian]. The article discusses the quantities of Sardinian iron ores available, their specifications and the potential quantities of electric energy. Results of electrothermic smelting tests carried out on these ores are described and the means of reducing power consumption are discussed. It is suggested that the lower grade ores could be economically smelted to pig iron and that certain selected ores could be used to produce haematite cast iron. (10 references).

Some Chemical Reactions Occurring in Pelletizing and Iron Ore Reduction. J. O. Edström. (*Jernkont. Ann.*, 1958, **142**, (7), 401–460, discussion 460–466). Gaseous diffusion and flow through porous material, gas-solid reactions, solid-solid reactions in oxide systems and solid state diffusion studies have been made. Pelletizing studies were made on magnetite oxidation and on lime–haematite reactions, and quantitative formulations of the oxidation of ores in pure O_2 and O_2-inert gas mixtures were arrived at. The CaO–Fe_2O_3 phase diagram was revised, a CaO, $2Fe_2O_3$ phase was found. Reduction studies were carried out on pure crystallites of iron oxide and the results were applied to concentrates and lumps. The reduction of ferrites was also examined as a model for impure ore or sinter. Two-phase reduction zones are formed, dicalcium ferrite is reduced in one step, but monocalcium ferrite and calcium diferrite form up to seven zones, each representing one reduction step. The effects of small amounts of lime in rich ore pellets is discussed. (40 refs.).

The Influence of Mixture Composition on Sintering. G. Sironi. (*Metal. Ital.*, 1958, **13**, May, 181–190). [In Italian]. The author describes tests carried out on an experimental sinter plant with magnetite and pyrites cinders. Self fluxing sinters were produced with various degrees of basicity by adding limestone to the mix. It is thought that the results obtained will prove useful to industrial practice.—M. D. J. B.

Properties of Self-Fluxing Sinter. N. L. Goldshtein and N. S. Khromchenko. (*Stal'*, 1958, (7), 586–593). The reducibility of sinter mainly depends on the temperature of the sintering process and the amount of gangue in the sinter mix. These factors are roughly determined by the amount of bivalent iron in the total iron content of the sinter. The present investigations were intended to determine the concentration of combined iron oxides in various sinters by reduction at moderate temperatures.—R. S.

FUEL—PREPARATION, PROPERTIES AND USES

Choice of Blends of Coals in the Coke Ovens of the Lorraine Iron and Steel Industry. P. Foch and R. Busso. (*Rev. Ind. Min.*, 1958, **40**, Sept., 669–685). An extensive series of trials is reported.

Engineering Considerations with Particular Reference to New Coking Plant. H. Severs. (*Gas World.*, 1958, **148**, Oct. 4, 57–58). The use of spheroidal graphite iron for floor plates, door sections, diaphragms and braces is suggested.

Automatic Motion Recorder Applied to Movable Wall Test Ovens. W. C. De Sieghardt. (*Blast. Fur. Steel Plant*, 1958, **46**, Sept., 974–976). The recorder was designed for graphing the pressures developed during a "movable wall oven" test of a coal mix. An accurate direct-reading curve of the indicated pressure is produced by an electro-mechanical linkage.

Desulphurization of Coke by Hydrogen. H. E. Blayden. (*Coke Gas*, 1958, **20**, Jan., 26–29, 37). It is concluded that the process is too slow to be of commercial significance and the possibility of any useful method of sulphur removal is remote.

Reactivity of Coke: Procedure for the Measurement for Foundry Cokes. A. F. Boyer, G. Durand and P. Payen. (*Chim. Ind.*, 1958, **80**, Sept. 220–233). A process depending upon reaction with CO_2 is described. Apparatus for the treatment of 10–100 g. at temperatures up to 1500° C was developed.

AIR POLLUTION AND SMOKE

Air Pollution Review 1956–57. K. Kay. (*Ind. Eng. Chem.*, 1958, **50**, Aug., 1175–1179). (261 refs.).

The Significance of Particulate Emissions in Community Air Pollution. F. E. DeMartini. (*J. Franklin Inst., Monograph No. 4*, 1958, Mar., 3–17, discussion 18–20). Sources and effects and a list of U.S. air sampling stations and their findings and research programmes in hand are briefly outlined. **Qualitative and Quantitative Factors in Atmospheric Pollution Sampling.** J. Z. Holland. (21–33, discussion 34–36). Factors in the planning and carrying out of surveys are considered; 9 important variables are listed. **Characteristics of Equipment for the Removal of Particulate Matter from Gas Streams.** W. C. L. Hemeon. (61–72, discussion 73). Significant particle sizes (constituting a nuisance, not necessarily a health hazard) and factors in the design of collectors are discussed, with a note on measurement.

Calculation of Distribution of Dust and Gas. M. Dien and R. Trappenberg. (*Forsch. Wirts. Nordrhein-Westfalen*, 1957, No. 502, pp. 113). Formulæ for the spread of dust and gases depending upon wind and other factors are given and 67 graphs are shown for various values of the parameters.

Absorption of Sulphur Dioxide from Air. Oxidation in Drops Containing Dissolved Catalysts. H. F. Johnstone and D. R. Coughanowr. (*Ind. Eng. Chem.*, 1958, **50**, Aug., 1169–1172). Droplets of solutions of the sulphates of Mn, Fe, Cu, Ni or mixtures were examined.

Theory of Aerosol Filtration. S. K. Friedlander. (*Ind. Eng. Chem.*, 1958, **50**, Aug., 1161–1164). Examples are worked out. (23 refs.).

Experiments on an Industrial Venturi Scrubber. J. A. Brink, jun. and C. E. Contant. (*Ind. Eng. Chem.*, 1958, **50**, Aug., 1157–1160). Efficiencies in trapping fine dust and aerosols are measured. The material tried was a phosphoric acid mist.

Precipitation of Dust from Industrial Waste Gases by Means of the C.I.W.P. Siren. B. Maczewski-Rowinski. (*Polish Acad. Sci. Proc. II Conference on Ultrasonics*, 1957, 169–174). [In English].

Dust Piping Modifications to Prevent Material Buildup and Wear. R. C. Ortgies. (*Mod. Castings*, 1958, **34**, Aug., 80–82). Dust extraction design is discussed with regard to pipe gauge, hooding and velocities through openings, also elbow design. The ventilation of elevators, screens and sand bins is included.

REFRACTORY MATERIALS

Reactions Between Iron Oxides and Alumina–Silica Refractories. A. Muan. (*J. Amer. Ceram. Soc.*, 1958, **41**, Aug., 275–286). The system FeO–Fe_2O_3–Al_2O_3–SiO_2 is used to evaluate the attack on refractories by iron oxides. The extent of attack and nature of the products at various oxygen pressures are considered.

Phase Equilibrium Studies in the System CaO–Cr_2O_3–SiO_2. F. P. Glasser and E. F. Osborn. (*J. Am. Ceram. Soc.*, 1958, **41**, Sept., 358–367). The work has reference to steel furnace refractories.

Studies in the System CaO–Al_2O_3–SiO_2–H_2O: III. New Data on the Polymorphism of Ca_2SiO_4 and Its Stability in the System CaO–SiO_2–H_2O. D. M. Roy. (*J. Amer. Ceram. Soc.*, 1958, **41**, Aug., 293–299).

Fused Zirconia Refractories: I, Fusion of Zirconia and its Stabilization. O. Yonemochi, T. Abe and T. Yamada. (*Rep. Gov. Ind. Res. Inst. Nagoya*, 1958, **7**, Aug., 602–611).

Investigation of the Quartz–Cristobalite Transformation. III.—Investigations of the Transformation Behaviour of Silica Brick. H. E. Schwiete and H. Stollenwerk. (*Archiv. Eisenh.*, 1958, **29**, September, 595–598). The changes in mineral stability and the technical properties of silica brick were investigated by repeated firing under operation conditions. Firing trials on the individual grain size classes showed the existence of a clear relationship between grain and surface dimensions.

Refractoriness Tests Related to the CaO–MgO–SiO_2–Al_2O_3 system. R. Zoja. (*Met. Ital.*, 1958, **50**, March, 85–90). [In Italian]. The newly proposed method using spherical test pieces has been adopted to study the refractoriness of a portion of the CaO–MgO–SiO_2–Al_2O_3 system. The data collected on the behaviour of different mixes confirms the merits of the method which makes it possible to get information on the progress of the softening process.—M. D. J. B.

New Methods in Maintenance of Refractories in Steel Plants: IV. (*Ind. Heat*, 1958, **25**, March, 579–584). The advantages of using cast refractory-lined hot tops are considered.

Examination of Used Chrome–Magnesite Refractories by Petrological and X-Ray Techniques. A. G. Cockbain and W. Johnson. (*Trans. Brit. Ceram. Soc.*, 1958, **57**, Aug., 511–526). Methods are described. Roof refractories were examined and the general sequence of changes is described. It is suggested that the structure produced represents the approach of the composition to equilibrium with the furnace atmosphere. The hot-face constitution becomes more or less independent of the original brick composition, and this reconstruction is considered to be a major factor in brick failure.

Possibilities of Analysing Refractories by X-Ray Diffraction. E. Moltoni and G. Giuseppetti. (*Met. Ital.*, 1958, **50**, March, 91–100). The authors discuss the results of X-ray studies (powder spectra) on 54 crystalline compounds which may be of considerable interest for refractories. A thorough study of published work shows the possibility of studying refractories by X-ray diffraction analysis, particularly in the case of silica, silica-alumina, dolomite, magnesite, chrome–magnesite and special refractories. The advantages of the method are discussed. (47 references).—M. D. J. B.

Study on the Resistance of a Silico-Aluminous Refractory Submitted to Sudden Cooling. L. Massimilla and S. Bracale. (*Met. Ital.*, 1958, **50**, March, 101–105). Reference is made to previous research and to the two theories which enable estimates to be made of the behaviour of refractory materials submitted to sudden changes of temperature. These are: the theory of the highest stress and Weibull's statistical theory. A brief account is given of the experimental technique adopted in testing some silico–aluminous refractory panels submitted to sudden cooling. A comparison is made between the behaviour of the panels under test and the forecast of behaviour as suggested by the two theories mentioned above.—M. D. J. B.

IRON AND STEEL, GENERAL

Some Impressions of the Continental Steel Industry. G. R. Bashforth. (*Metallurgia*, 1958, **58**, Sept., 135–140, 142). An account of modern developments and practice in iron and steelmaking on the Continent, as seen on a visit by the author.

A Review of European Steel Plant Progress—1957. R. C. McMichael. (*Iron Steel Eng.*, 1958, **35**, Aug., 73–77). A report of a visit made by a group of Lukens steel executives to European steel plants.

Progress and Trends in the French Iron and Steel Industry. F. Colombey. (*Rev. Ind. Min.*, 1958, **40**, Sept., 717–724). The survey covers work since 1952 and then looks forward. After a table of output of metal, ingots and plate, tube and wire, brief accounts of advances in coke oven practice, basic Bessemer operation, the newer iron processes (L. D., Kaldo etc.), and casting and rolling practice are given.

Kaiser Steel Appropriates $214 000 000 to Expand Its Services to the Growing West. C. Longenecker. (*Blast Fur. Steel Plant*, 1958, **46**, Aug., 814–863). Plans for the Fontana plant of which construction started in April, 1942 are reviewed. Coke ovens, blast furnaces, basic oxygen steel plant, O.H. furnaces, soaking pits, blooming, plate, structural, merchant and skelp, electric weld pipe, continuous weld pipe, cold rolling and hot strip mills and finishing lines, the tin plate mill and departments and services are all described.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

The Metallurgical and Economic Effect of Steam Injection in Blast Furnace Operation. O. Farkas. (*Koh. Lapok*, 1958, **13**, April, 186–190). In this second part of the paper the author deals with the temperature of blast, the effect of steam injection on the oxidation zone and blast composition, as well as its influence on the economy of pig iron production. Steam injection regulates smelting in the blast furnace effectively, especially under unsatisfactory operation conditions.—P. K.

Towards Blast Furnaces Without Wear and Without Hanging. G. Grenier. (*Echo Mines*, 1958, Mar., 156–158). A review and discussion of the work of Archibald, Brown and Leonard. (*J.I.S.I.*, 1957, **187**, Sept., 32–45).

A Short Description of the Danube Iron and Steel Works. F. Árkos. (*Koh. Lapok*, 1957, **12**, Aug.-Sept., 332–336). The Danube Iron and Steel Works in Dunapentele, Hungary is planned for producing more than 1 million tons O.H. steel p.a. in plates, sheets and strip. The works produces coke from Hungarian coal and makes pig-iron too. At the present time only one range of coke ovens is ready out of the four planned. One 700 m^3 blast furnace is finished out of the five contemplated and it will produce about 280,000 t pig iron. The 600-t roll mixer is not yet completed. Out of the nine 125-t O.H. furnaces planned, there are at the present time only three ready and in production. The construction of the rolling mill is only in a preliminary stage. The author gives a quite comprehensive description of the present and future plants in these new iron and steel works.—P. K.

Experiences with the Blast Furnace in the Danube Iron and Steel Works. L. Marczis. (*Koh. Lapok*, 1957, **12**, Aug.-Sept., 384–390). The author describes the blast furnace, its starting up and the production of pig iron in the Danube Iron and Steel Works in Hungary. He refers to new techniques applied there, such as: slightly acid slag, low Mn-containing pig iron and the desulphurizing of the latter with lime powder outside the furnace. Experiments with high top gas pressure will also soon start.—P. K.

Sintering for Fluxless Smelting. E. Mazanek and R. Benesch. (*Hutnik*, 1957, **24**, May, 181–186). [In Polish]. The efficiency of the blast furnace can be increased by preparation of a self-fluxing charge of suitable composition. Even very poor iron ores mixed to form a self-fluxing charge, can be smelted economically. This method has led to a higher productivity of the blast furnace (10%–15%), reduction of coke used, and reduction of pig iron by 80–100 kg/t.

Techniques in Rebuilding a Blast Furnace. C. F. Bessent. (*Iron Steel Eng.*, 1958, **35**, Feb., 82–94). Particulars are given of the detailed planning and teamwork required for rapid dismantling and relining of a blast furnace. Special items are oxygen lancing to tap the salamander into a special bed; not blowing down to lower the stock level, to maintain production, avoid troubles with top temperature, and help to distribute water; flooding-down with water; blasting to remove tuyere and bosh walls; blasting solidified metal in the bottom; and bricking the stack while the hearth is being torn away. A 24 ft 6 in. hearth furnace was rebuilt to 25 ft 6 in. in 34 days.—E. E. J.

Disturbances in Blast Furnace Operation. L. Ya. Shparber. (*Metallurg*, 1957 (1), 2–9). Causes of disturbances in the operation of

blast furnaces and methods which can be used to restore normal operation are discussed.

Development of Blast Furnace Tuyeres at Wheeling Steel. E. P. Quick. (*Blast Furn. Steel Plant*, 1958, **46**, Mar., 307–309). Changes in tuyere design at this plant have increased tuyere life considerably. Tuyere changes can now be made during a scheduled shut down and delays due to tuyere changes average 8½ min per furnace per month.—B. G. B.

Basic Problems in Regulating the Operation of Blast Furnaces. L. Ya. Shparber. (*Metallurg*, 1956, (5), 3–7). It is stated that high output and economy in operation of blast furnaces can be achieved only if the burden descent is uniform. Main causes of disturbances in furnace operation are discussed. A list of symptoms of disturbances in the furnace operation and preventive measures is given.—V. G.

Instrumentation for Giant Turbo-Blower at Appleby-Frodingham. (*Brit. Steel.*, 1958, **24**, Mar. 86–87). The 'E' blower at Appleby-Frodingham blast furnaces, the largest steam-driven turbo-blower in the world, can deliver 160,000 ft. free air per min at 35 p.s.i. The plant also has 4 smaller blowers to serve the 4 blast furnaces, and E blower may be used alone or in conjunction with these ("split-wind blowing"); the instrumentation which can control any of the systems of blowing is described. The flow instruments on each blower are compensated for temperature and pressure, so that measurements can be summated.—D. L. C. F.

Visit of a Belgium-Luxembourg Steelmaking Delegation to the U.S.S.R. between 27 August and 11 September 1956. M Peters. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, **4**, (10), 2063–2073). Information concerning Russian blast furnace practice obtained during the visit is described. Details of burden preparation, furnace lines and outputs, high top pressure and blast humidity are given.

Acid Smelting of Lorraine Ores. C. G. Thibaut. (*Centre Doc. Sidér. Circ.*, 1958, **5**, (2), 357–365). The influence of slag basicity on coke rate and sulphur and Si content of hot metal is discussed. Reference is made to British and French practice. Coke rate is found to diminish with decrease in slag basicity. In the case of Lorraine ores, where slag volume is almost independent of slag basicity there is a saving of 1 to 2% in coke rate for a decrease in CaO/SiO_2 ratio of 0·10. Acid practice gives rise to hot metal with a low Si content.

Increasing the Life of Top Charging Gear of Blast Furnaces. M. A. Tylkin, I. F. Parfent'ev and V. I. Sivak. (*Stal'*, 1958, (3), 207–208). Hard-facing of surfaces or the use of all-cast flexible hoppers and rigid bells are described. The welding and hard facing processes are given.—R. S.

Charging System for a Large Blast Furnace. P. S. Balevich. (*Metallurg*, 1957, (1), 11–12). A large furnace of 2000 m³ working volume would require a radical change in charging equipment. A system of charging based on conveyors is proposed. A brief description of the proposed system is given.—V. G.

Distributing Device for Blast Furnace Throat Closure. Z. Krotkiewski. (*Hutnik*, 1957, **24**, Feb., 47–51). [In Polish]. The author discussed the apparatus designed by Brown, Becket and McKie, and describes two versions of his own distributing device. In order to test this device, the Institute of Metallurgy at Gliwice built a model (scale 1 : 12). The results obtained from the model were quite satisfactory. A larger model (scale 1 : 8) is now in operation.

Comments on A. S. Ayukov's Paper "New Design for Blast-Furnace Burden Distributors. N. P. Sapozhnikov. (*Stal'*, 1958, (3), 208).

Operating Conditions in the Space Between the Large and Small Bells in a Blast Furnace. L. A. Lepikhin. (*Metallurg*, 1957, (1), 13–14). Changes in the gas composition, pressure and temperature in the space between bells during various charging sequences were investigated. On the basis of the results obtained some possible measures leading to steam economy are proposed.—V. G.

Processes in the Blast Furnace Hearth When Working at High Top Pressure. B. F. Goncharov. (*Stal'*, 1958, (2), 97–104). A furnace working at 0·7 atm. top pressure showed a drop of ~ 3% in the direction of the axis of the hearth but no substantial radial pressure difference. CO in the gas between the tuyeres varies radially increasing towards the axis. Change over to high top pressure and to self-fluxing sinter improves oxide reduction above tuyere level. Oxide in the slag is increased 6–9 times in the oxidizing zone and outside it by 1½–2½ times. Slag formed above tuyere level contains 2·5% SiO_2 and 5% CaO less than slag at tapping. 11·5–41·7% of Mn oxide reaching tuyere level is not reduced. Si is high above tuyere level but is intensively oxidized in the oxidizing zone. Metal formed above tuyere level contains 75% of the iron at tapping. In the oxidizing zone much C is oxidized but beyond it content approaches that of the iron as tapped. Desulphurization is completed below tuyere level.—R. S.

Introduction of Powdered Fuel Through the Tuyeres into the Hearth of a Blast Furnace. V. I. Loginov, G. G. Oreshkin, I. G. Polovchenko, A. A. Sorokin and I. N. Kardasevich. (*Metallurg*, 1956, (4), 10–12). Experimental blowing through the tuyeres of powdered anthracite into the hearth of a blast furnace producing ferro-silicon is described. The powdered fuel was carried by compressed air from two specially arranged railway tanks of 15m³ capacity each, into a cyclone from which it was blown into tuyeres. Blast temperature was increased to compensate for the cooling effect of the blown-in fuel. The supply of fuel to the hearth was intermittent at a maximum rate of 20 t/hr. It is claimed that the consumption of coke during experiments decreased approximately by an amount equivalent to the amount of powdered fuel introduced into the hearth. The paper is accompanied by an editorial note indicating that the duration of the tests was insufficient for the evaluation of the effect of blown-in fuel on the coke rate.

The Automatic Regulating Device for the Blast Furnace in the Danube Iron and Steel Works. L. Marczis. (*Koh. Lapok*, 1957, **12**, Aug.-Sept., 390–396). A detailed description is given of the automatic regulation of the blast furnace in the Danube Iron and Steel Works in Hungary.—P. E.

Split Wind Blowing Increases Furnace Production. (*Iron Steel Eng.*, 1958, **35**, Feb., 174, 177). The system links two 110,000 ft³/min turbo-blowers and one 50,000 ft³/min turbo-blower, delivering up to 90,000 ft³/min to each of three blast furnaces at Aliquippa Works.—E. E. J.

Centrifugal Blower for the Blast Furnace. (*Fonderia*, 1957, **6**, Jan., 39). [In Italian]. A brief description is given of the steam turbine blast furnace blowing unit recently installed at the Société Metallurgique d'Esperance-Longdoz in Belgium. The dimension of the furnace and specifications of the blower are given.—M. D. J. B.

The Use of Steam-Air Blast in Blast Furnaces. V. Ya. Miller and S. A. El'kin. (*Stal'*, 1958, (3), 193–202). A method of investigation is described which shows the influence of the nature and composition of the gas stream and the rate of reduction of iron oxide under conditions of diffusion. Increased H_2 by 1% which is equivalent to 10 g/m³ increased blast humidity increases the reduction rate at 800–1000° by 4·7%. The compensating temperature rise to make up for the dissociation of steam at the hearth averages 4·7° C per g moisture per m³ and so the limiting factor is the reserve of blast heating. Otherwise steam can be used only to make uniform the natural air humidity, however this enables blast temperature to be raised with reduction of coke consumption. The linear velocity of the gas stream within the limits of 6–29 m/sec has no effect on the rate of reduction.—R. S.

The Humidifying of the Blast in the Blast Furnace. Z. Rychlik and W. Sabela. (*Hutnik*, 1957, **24**, April, 147–153). [In Polish]. The author discusses the conditions and results of the use of humidified blast based on the trials in one of the "POKOJ" furnaces. He describes methods of measuring moisture in the blast and then gives a detailed description with diagrams of different hand-operated and automatic devices used for regulation of the humidity.

Significance of the Low-Shaft Blast Furnace in Smelting Work. L. Visnyovszky. (*Koh. Lapok*, 1957, **12**, June, 221–227). Based on foreign experiments, the author states that the problem of pig-iron production in low-shaft blast furnaces of 60–100 t capacity per day is technically solved. The production is only made economical by blowing air enriched to 35–40% O_2 content. If the top gas of a residual heat of combustion 1700–1800 Kcal/m³ can be fully utilized for other metallurgical purposes, the fuel consumption of the pig iron production is less than half that of the low-shaft furnace. The top gas is sulphur-free. Hungarian coals from Pécs and Komlo, and cokes or semi-cokes with 15–20% ash and a particle size of 5–20 mm, made from well washed Hungarian brown coal, are suitable for this method. It is possible to meet in this way the whole Hungarian foundry pig requirements from native raw-material such as red mud and calcined pyrites.—P. E.

Examination of Dust Formed in a Thomas Blast Furnace. A. Dufraine and P. Charotte. (*Centre Doc. Sidér. Circ.*, 1958, **15**, (3), 639–650). Experiments are described with the object of determining the size distribution, chemical composition and density of the dust found at different levels in the blast furnace, and the pressure, velocity and temperature of the gas at these levels.

Note Regarding the Entrainment of Dust at the Blast Furnace Throat. Erpelding. (*Centre Doc. Sidér Circ.*, 1958, **15**, (3), 651–661). See previous abstract. The results have been used to calculate the conditions of entrainment of dust by gas in the blast furnace throat.

On the Production of Pig Iron for Nodular Cast Iron and Effects of Minor Special Elements. I. Aoki and T. Tottori. (*Tetsu-to-Hagane*, 1957, **43**, Nov., 1191–1194). [In Japanese]. The occasional production in the blast furnace of iron unsuitable for making nodular iron (although within the specification for C, Mn, Si, P and S) was attributed to Sn, As, Sb etc., whose effects were enhanced by the 0·05–0·1% Ti always present. It is eliminated by using suitable ores.—K. E. J.

Smelting of Foundry Iron in Blast Furnaces of the Magnitogorsk Metallurgical Combine. I. I. Morev. (*Metallurg*, 1956, (5), 7–9). Slag practice and the method of transfer from the production of basic iron to foundry iron of large blast furnaces on the Magnitogorsk Metallurgical Combine is outlined.—V. G.

Exploitation of Hot-Cooling of Metallurgical Furnaces. S. M. Andon'ev. (*Stal'*, 1958, (3), 271–280). Blast furnaces, O.H. furnaces, rolling mill reheating furnaces and electric ferro-alloy furnaces are reviewed. Advantages compared with water cooling are noted and detailed diagrams are shown.—R. S.

A Survey of the Constructional Development of Cowper Stoves from Practical Results and Research. U. Steffes, A. Graff and J. Paquet. (*Rev. Tech. Luxembourg.*, 1957, **49**, Oct.-Dec., 209–216). Historical developments of regenerative and recuperative stoves in the light of experience and research are discussed. Future developments of the Cowper stove are indicated.—R. P.

Mechanical Packing of a Blast Furnace Stove Burner. B. I. Ginzburg, A. K. Vulykh, I. I. Liscenko and D. G. Klimenko. (*Metallurg*, 1958, (3), 7–10). A mechanical self-tightening packing device with removable connections was developed to prevent gas and air leakages at the contact between valve and stuffing box.—R. S.

The Use of Dinas Bricks for Checkers of Blast Heating Stoves. I. D. Lychak. (*Metallurg*, 1956 (5), 37–38). Replacing chamotte checkers by Dinas refractory bricks improved the service life of blast heating stoves by a factor of three. Some details of the method of laying Dinas checkers are given.—V. G.

Results Obtained From Automatic Stove Changing in Western Germany. E. Sanfter and L. Fuchs. (*Blast Furn. Steel Plant*, 1957, **46**, Jan., 63–69). The influences of blast temperature and of the oxygen and steam content of the

blast on blast-furnace operation are discussed. German stove design, and in particular automatic stove changing, is reviewed.—B. G. B.

Automatic Control of Gas Distribution in Blast Furnace Stack. I. A. Suchkov and V. V. Burtsev. (**Stal'*, 1958, (2), 110–113). An automatic sampling and recording system was installed in 1953. Radial temperature measurement in the stack and automatic control of gas distribution from CO_2 content are described. The thermocouple control circuit and recording instruments are also shown.—R. S.

The Treatment of Siliceous Iron Ores by the Krupp-Renn Process. W. Küntscher, S. Henkel and J. Schleier. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, **4**, (10), 1945–1969; *Bergakademie*, 1955, **7**, (11), 514–526). A description of the principles of the process is given. The influence of slag composition is discussed. Operating data obtained from a range of ores are given and show the scope of the process. Reactions occurring in the different zones in the kiln are considered. Balances for iron, sulphur, phosphorus carbon and for heat are drawn up.—B. G. B.

The Metallurgy of High Purity Iron. I. B. Vécsey. (*Koh. Lapok*, 1957, **12**, Jan.-Feb., 18–24). In this part of the paper the theoretical principles and practical methods of the production of iron sponge are given.—P. K.

Investigation into the Reduction of Iron Oxides by Graphite. V. I. Arkharov, V. N. Boloslovskii, M. G. Zhuravleva and G. I. Chufarov. (*Zhur. Fiz. Khim.*, 1955, **29**, (2), 272–279). [In Russian]. The experiments were made at temperatures between 1000 and 1150°, when the reduction of the oxides by solid reducing agents proceeds by way of the gaseous carbon oxides which are formed by the interaction of CO_2 with carbon. X-Ray microstructure investigation of the solid phase has revealed that in the reduction of iron oxides by graphite, the crystal and chemical transformations play an important role.

The Application of Oxygen to Crude Iron Production in the Low-Shaft Furnace. K. Säuberlich, H. Grohmann and G. Richter. (*Neue Hütte*, 1958, **3**, April, 225–232). The theory of oxygen enrichment in the blast is discussed with reference to its effect on combustion, gas, and temperature conditions in the furnace. Pilot-scale experiments with blast oxygen contents of up to 35% are reported. Results of large-scale experiments at Donauwörth are discussed. With a blast oxygen content of 25%, iron production was increased by 25·9%; coke consumption dropped by 6·1%. Extensive experiments on spiegeleisen production with a blast oxygen content of 24·5% are described.—L. J. L.

PROPERTIES, TREATMENT AND USE OF SLAGS

The Use of Blast Furnace Slag in Agriculture. I. Pálfalvy. (*Koh. Lapok.*, 1958, **13**, April, 196–200). In this first part of the paper, suggestions are made for practical experiments in agriculture with blast furnace slag of adequate grain size and sufficient CaO + MgO content for improving soil. The propositions are based on theoretical considerations and literature publications. A granulated unground slag seems to be unsatisfactory for this purpose.—P. K.

Studies on Converter Slags. II. On Crystals Precipitated from Molten Slags. I. Kushima, T. Amanuma and S. Enomoto. (*Suiyokwai-Shi*, 1957, **13**, Dec. 327–330). Crystals of fayalite containing magnetite separate in a CO–CO_2 atmosphere.

Viscosity Studies on the System CaO–SiO_2–Al_2O_3 and their Bearing on Direct Process Slags. J. Schleier. (*Neue Hütte*), 1958, **3**, May, 282–293). The structure of slags and methods of viscosimetry are briefly surveyed; a rotating cylinder viscometer is described; synthetic slags of the system CaO–SiO_2–Al_2O_3 have been studied: viscosity diagrams for 1300, 1400 and 1500° C are presented. MgO was found to reduce viscosity a little more than CaO.—L. J. L.

PRODUCTION OF STEEL

Advances in Steel Technology in 1956. (*United Nations* E/ECE/305; E/ECE/Steel/119, 1958, pp. 107). **Review of the Iron and Steel Industry, 1956.** I. P. Bardin (1–21). This is a review covering several years up to 1956 and briefly reviews the industries of Europe and the U.S. as well as the U.S.S.R. giving numbers of plants, size and capacities of furnaces and other equipment and some statistics of output. **Stirring in Steel Production: Mechanical Stirring as Opposed to Inductive Stirring.** A. Færden. (66–86). The development of electric steel production is surveyed and stirring processes are fully treated not only mechanical and inductive but also by blowing with gases or metal vapours, reladling and the use of rotary furnaces. Comparisons are given between the effectiveness of the methods. (33 refs.). **Continuous Casting of Steel.** (87–102). An account of installations, mainly in the U.S.S.R. with plans and illustrations and a table of all plants working in 1956 and their products.

Contribution to the Metallurgy of the Basic Converter Process. H. Beck. (*Tech. Mitt.*, 1957, Dec., 245–269.) This paper gives details of tests and results obtained with a basic converter. Changes in composition during blowing, initial composition and temperature, the influence of scrap additions, blast pressure and casting temperatures are discussed, also how initial silicon content and pre-heating of the pig to 1220° C aid dephosphorization. (62 references).—R. P.

Some Recent Changes at Hagondange Steelworks (U.C.P.M.I.). J. de Hedouville. (*Centre Doc. Sidér. Circ.*, 1958, **5**, (2), 371–376). Details are given of changes in convertor design which have recently been introduced at Hagondange. The convertor lines, tuyere arrangement, compaction of the convertor hearth, and brick handling have been altered. The effect of these changes has been to reduce the blowing time by 23% and to increase the lining life.—B. G. B.

The Optical Properties of Iron–Oxide Vapour. W. Pepperhoff and C. Passow. (*Arch. Eisenhütt.*, 1958, **29**, Feb., 77–82). In the decisive phase of the basic Bessemer process, converter flame radiation is determined by the optical properties of brown iron oxide vapour. These have therefore been investigated in detail, with particular reference to absorption and scatter characteristics as a function of vapour particle sizes below the dimensions of light waves. Exact determination of extinction values of iron oxide vapour provides a simple method of measuring the amount of smoke developed in the converter.—L. J. L.

Open-Hearth Steel Plant in the Danube Iron and Steel Works. L. Éles. (*Koh. Lapok*, 1957, **12**, Aug.-Sept., 397–403). The author describes the scrap yard, the charging floor, the construction and heating of the furnaces, the casting bay and the steel making technique in the O.H. steel plant of the Danube Iron and Steel Works in Hungary.—P. K.

The New Open-Hearth Steel Works III of the Hoesch-Westfalenhütte AG., Dortmund. H. von der Warth, G. Henke, E. Wiegand and W. Nellen. (**Stahl u. Eisen*, 1958, **78**, Jan. 23, 79–87). Layout, construction, mode of operation and output rates of the new O.H. steel works are described. At present two furnaces of 150–180 t capacity each are in operation, they can be alternatively gas- or oil-fired, the hearth area is 60 m². Hot-cooling is employed with steam of 32 atm. at 325° C. The results obtained during the first year of operation and the repairs necessary to the furnaces are described. An increase of 2·5 times of the output per man employed as compared with the old steel works was achieved.—T. G.

Russian Experience with 500-ton Open Hearth Furnaces. R. Sewell. (*Iron Steel*, 1958, **31**, Feb., 61–62). Details and sectional drawings are given of the 500-t O.H. furnace at the Voroshilov plant in Russia. Particular features are its fully automatic control, the feeding of oxygen to both flame and bath, and the mobile slag pockets. The results of the first campaign are summarized, and improvements to be made are noted. An indication is given of similar furnaces scheduled for the Russian industry.—G. F.

Industrial Furnace Practice. H. Schwiedessen. (*B.W.K.*, 1958, **10**, Apr., 185–186). A brief review with plans of an O.H. furnace. (37 references). (The occasion of the Review No. is the Hannover Fair 1958).

Gas Atomizes Open-Hearth Fuel. V. B. Thompson. (*Steel*, 1958, April 14th, 144–146). At a Mansfield, Ohio, steel plant, high pressure (200 psi) natural gas is used to atomize fuel oil entering the furnace combustion chamber. Advantages over oil–steam firing are described.

The [Economic] Position of the Open Hearth Furnace. G. Grenier. (*Echo Mines*, 1958, Apr., 231–233). The development of other processes is briefly noted and the growth of the O.H. furnace and factors in its productivity are reviewed.

An Installation for the Automatic Cut Off of Fuel Oil at Atomisers of Open Hearth Furnaces. N. S. Bugrov. (*Metallurg*, 1956, (6), 38–40). An installation for the automatic cut off of fuel from idle atomisers after reversals is described.—V. G.

Some Special Features of Smelting Steel in Open Hearth Furnaces. G. E. Ovchinnikov. (*Metallurg*, 1956, (5), 11–13). The operating practice of No. 3 melting shop on the Magnitogorsk Metallurgical Combine is described. The characteristic feature of the practice is low manganese content of metal (after melting 0·02–0·05%).—V. G.

The Use of Manganese Ore in the Scrap and Ore Process. E. D. Akol'tsev and V. B. Kaplun. (*Metallurg*, 1958, (3), 11–13). The O.H. plant at Kramatorsk produces killed and rimming carbon steels in 120-t furnaces fired with hot gas (1430 kcals (m³ and containing 0·5% H_2S). Average heat input is 14,000,000 kcals/hr. The operation of these furnaces without a mixer and with a sulphurous oil and charging 10 to 15 t of sulphurous scrap produces high meltdown sulphur. In order to remove sulphur and to slag silica, up to 16 t of limestone must be added and the slag must be "diluted" by manganese ore and bauxite during melt-down and the ore boil. Trial heats were produced in which 2 to 4 t of manganese ore were charged under a layer of limestone, the limestone addition being reduced by 4 to 5 t and the bauxite addition by 1 to 2 t. Three types of trial heats were produced to study the effect of manganese ore on furnace productivity, bottom life and metal quality. The layers of charge in the furnace, starting from the bottom, were: iron ore (5 to 6 t), crop ends (10 to 15 t), manganese ore (3 to 4 t), limestone and the remaining iron ore, steel scrap. The improvements achieved are described.—R. S.

Relation Between the Melting Process in the Basic Open Hearth Furnaces and the Erosion of Linings. Gh. Gh. Chitu. (*Met. Constr. Masini*, 1958, **10**, (1), 17–20). The manner in which the furnace is driven influences not only the quality of the steel but also the life of the linings, especially those of the hearth. Here the corrosion is especially related to the basicity of the slags, to the temperature maintained in the process, to the amount of fluorine introduced and to the duration of the various periods of the process. In 60-t O.H. furnaces an average of 51% of the total corrosion occurs before the complete melt-down and the balance of 49% occurs between melt-down and tapping. 23–25% of the total corrosion takes place in the zone of the slag, and elsewhere the corrosion is proportional to the area of contact between liquid and hearth.

Method of Melting Austenitic Cr–Ni Steels Using Oxygen, with High Recovery. T. Mazanek, J. Natkaniec, Z. Kosiewicz and A. Wolkenberg. (*Arch. Hutn.*, 1958, **3**, (1), 3–36). Oxygen refining requires a high temperature bath and probably a thin layer of slag. Experiments are reported with attention to control and to lining conservation and another series on increasing Cr recovery and decreasing tap-to-tap time and consumption of power. A 6-t arc furnace was used. About 2% Si and 1% Mn are required for high Cr recovery. (17 references).

The Use of Oxygen in Open-Hearth Works. W. Gerling and K. O. Zimmer. (*Stahl u. Eisen*, 1958, **78**, Feb. 6, 156–160). The various applications of oxygen in O.H. furnaces are described. The best utilization of oxygen is, however, its use in the gas producer.—T. G.

Works Data of O.H. Furnaces Heated with Cold Coke-Oven Gas in the Danube Iron and Steel Works. G. Repasi. (*Koh. Lapok*, 1957, **12**, Aug.-Sept., 403–410). Reference is made to Hungarian experiments on heating O.H. furnaces with cold coke-oven gas and oil additions. For improving the results, desulphurization of the gas, increased gas pressure and modification of the furnace design are necessary.—P. K.

Aerodynamic Constitution of the Open-Hearth Furnace. VIII. Conclusions. H. A. Hasimoto. (*Tetsu-to-Hagane*, 1957, **43**, Nov., 1194–1199). [In Japanese]. The work leads to relationships giving standard dimensions and production parameters in terms of the required productive capacity of a single air-uptake furnace. The standard design lays down a system of mixing air and fuel based on jet intensity.—K. E. J.

Deoxidation of Low Alloy Steels with a Saving in Ferro-Alloys. I. M. Leikin. (*Metallurg*, 1958, (3), 13–16). Si–Mn, Fe–Mn or blast furnace Fe–Si are usually used. The best quality steel is obtained with Si–Mn, but the method of adding Fe–Mn and blast-furnace Fe–Si with prior deoxidation was found to produce a steel equal to that deoxidized in the furnace with Si–Mn with a Mn : Si ratio of 3 or 4 : 1. Si–Mn is in short supply and blast furnace Fe–Mn should be used where possible. For deoxidizing steel with 0·12–0·15% C part of the Si–Mn can be replaced by Fe–Mn added to the bath at the beginning and following with Si–Mn after several min. Use of Mn ore economizes Fe–Mn and Si–Mn; it is added after slag is removed during build up of the record slag. At Alchevsk with the scrap and ore process it is found that if 0·8–1·0% of Mn ore is added during the build-up of the slag the Mn content before deoxidation reaches 0·28–0·32% with about 0·1% C. Killed steel is now made without prior deoxidation, tapping on the boil, reducing tap-to-tap time, cost of steel and content of P, H_2 and non-metallic inclusions. Most low-alloy steels are deoxidized in the ladle with Al and Ti.—R. S.

French High-Grade and Special Steels and the European Economic Community. R. Morizot. (*Mét. Constr. Mécan.*, 1958, **90**, Apr., 237–239). The probable effects of the integration arrangements made with a view to the setting up of a common European market are analysed, from the point of view of the financial repercussions on the French high-grade steel industry, and the supply of alloys.

Notes on the Nature and Manufacture of Quality Steel. R. Guevara Lizaur. (*Tecn. Met.*, 1957, **13**, May-June, 110–136; July-Aug., 168–185; Nov.-Dec., 256–271). [In Spanish]. The origin and meanings of the term 'quality steel' are discussed; the author points out that 'body,' 'insensibility' and 'resistance to brittle fracture' are names for the same property. Tenacity is a fundamental property of quality steel and the influence of such factors as inclusions, ghost lines, ingot shape etc. is discussed. In the second part, the solidification process is examined in detail and reference is made to vacuum casting techniques, continuous casting, centrifugal casting and the use of rare earths with regard to quality steel production. Finally steel making is considered and slag-metal reactions are discussed in detail. (62 references).—P. S.

Experience in the Production of Chromium–Nickel Steel with a Chromium Content in the Charge up to 1·50%. P. K. Morokov and B. G. Petukhov. (*Metallurg*, 1956, (6), 20–23). In order to utilize alloy scrap and to study the possibility of producing Cr–Ni steel from charges containing up to 1·5% Cr 8 experimental heats of 12 Kh3A and 20Kh3A steels were carried out in 185-t O.H. furnaces with chrome–magnesite roofs. The composition of charges as well as compositions of metal and slag during individual smelting periods are given. It is stated that in order to obtain normal operation, burnt lime instead of limestone should be used. No operational difficulties were encountered and the quality of the metal produced was satisfactory.—V. G.

Melting and Casting of High Chromium–Nickel Molybdenum Steels. V. I. D'yachkov, P. V. Umrikhin, S. G. Claserev and I. G. Fadeev. (*Stal'*, 1958, (2), 120–126). Addition of 25–27 kg/t of Fe–Cr to the boiling bath causes no marked changes or difficulties in producing the heat. Alloying during the boil with subsequent deoxidation makes it possible to obtain a higher metal temperature before tapping than does alloying the deoxidized bath and also facilitates floating up of inclusions. The use of frames during casting while observing the rise of the metal in one of the moulds made possible an improvement in billet surface and reduction of hair cracks. The final process is described. Carefully dephosphorized metal with addition of red-hot Fe–Cr in 2–3 positions at intervals of 5–10 min and boiling for 30 min gave a C drop of 0·12–0·20%/h. At the right C content 2·5–2·8 kg/t of 33% 75% Fe–Si, 21% Al, 23% coke breeze and 23% ground lime were added and also 2·5–3 kg/t 45% Fe–Si and the metal further deoxidized with 16–18 kg/t blast furnace Fe–Si. The required Fe–Cr was added 10–15 min later. The second portion of the deoxidizing mixture (2–2·5 kg/t) was added before tapping, and in the ladle, Fe–Si (45%) and Al. Thus about two-thirds of the Fe–Cr is added during boil. Other features of the process are noted.—R. S.

Alloyed Steel in the Ukraine. D. Swan. (*J. Met.*, 1958, **10**, Mar., 185–186). An account of a visit to Dnieperprestoye and Zaporozhe briefly mentioning processes and equipment. U.S. and U.S.S.R. practices for 18–8 are compared.

The Production of Stainless and Acid-Proof Steels. E. Weigl. (*Koh. Lapok*, 1957, **12**, July, 275–286). The author briefly discusses the corrosion and passivity, chemical composition, mechanical and other properties of various stainless and acid-proof steels. He refers to the Hungarian edge-holding, stainless blade steel "Oxys" of the following chemical composition: C 0·65, Cr 16, Mo 1·5–2%. Afterwards he describes the production, hot-working and forming, annealing, pickling, deep-drawing, grinding, polishing and cold rolling of acid-proof stainless steels. Finally he comments on the state of stainless and acid-proof steel production in Hungary.—P. K.

Production of Transformer Steel by Mixing Open Hearth and Electric Steels. G. Vozny. (*Stal'*., 1958, (3), 225–226).

Investigation into Ingot Moulds. J. Duflot. (*Centre Doc. Sidér. Circ.*, 1958, **5**, (2), 407–418). A summary of the conclusion of a comprehensive investigation into ingot mould design is given. Recommended designs and compositions for moulds are shown in detail. A comparison is made between British and French ingot mould design.—B. G. B.

Evaluation of the Average Life of Ingot-Moulds by Means of Mathematical Analysis. B. Körös, K. Kollár and E. Chapo. (*Koh. Lapok*, 1957, **12**, Jan.-Feb., Öntöde, 20–27). The authors report the paper of K. F. Lane: "Theoretical Analysis of Recurring Failures in Steelworks," published in Iron and Coal, 1955, May, and extend the method of the English author for investigating the influence of other factors upon the life of ingot-moulds. They assert that the optimum corner thickness of the mould can only be determined by considering simultaneously the production costs.

Steel Moulds for Uniform Heating of Their Working Surfaces. J. Přibyl. (*Hutník*, 1957, **24**, April, 133–138). [In Polish]. The determination of durability of steel moulds from the ratio of the weight of the mould to the weight of the casting (K/J) is found to be quite inaccurate. Uniform heating of the working surfaces of steel moulds is considered one of the most important factors in durability. Such a condition can be obtained by construction of the moulds with varying wall thickness. Cracking of this type of mould can be prevented by suitable material structure and the choice of an optimum ratio K/J.

Increasing the Life of Large Ingot Moulds by Reinforcement. I. E. Brainin, I. I. Bornatskii and K. S. Alferov. (*Stal'*, 1958, (3), 267–270). Steel strapping increases the life 2·2–2·5 times depending on size and position. Cross-section must be sufficient to resist maximum tensile stress at outer surfaces during heating after filling. The moulds (6–7-t) are described and the strapping is shown. Formulae for calculating stresses are given. Data on mould consumption are added.—R. S.

Contributions to the Establishing of a Relation Between the Life of the Ingot Moulds and the Quality of the Cast Iron for Ingot Moulds. T. Dumitrescu. (*Rev. Mét. Bucarest*, 1956, **1**, 55–62). Conical ingot moulds of square section weighing 3600 kg were used for steel casting. Compositions are given and life was correlated with Si, Mn and S contents. The life was a minimum with a ratio of Si to free Mn of 7–9. Best results were obtained with increased Mn bringing the ratio near unity.

Improvement in Bottom Pouring by the Use of Monobloc Tubes. M. Fauchon. (*Centre Doc. Sidér. Circ.*, 1958, **5**, (2), 419–424). A description is given of the conventional method of construction of tubes for bottom pouring of ingots. The difficulties encountered are explained and details are given of a new monolith construction, developed at Valenciennes (USINOR), which has been found to have considerable advantages over conventional construction.—B. G. B.

Titanium-Bearing Stainless Steel: "Slag Washing" Process. (*Iron Coal Trades Rev.*, 1958, **176**, Mar. 28, 751). A method for preventing inclusions, banding and segregation by the use of a special separately melted slag added before teeming is outlined.

A Decrease in the Proportion of Metal Lost in Crop Ends. B. I. Panich. (*Metallurg*, 1957, (1), 36). The introduction of ingot moulds with a spherical bottom decreased the proportion of metal lost in "fish tail" from 2–4% to 1%.

Chemical Capping of Ingot Tops. J. de Hedouville. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, **4**, (12), 2431–2437). The technique described is applied to normal rimming steels. Al bars attached to a steel rod are plunged into the head of the ingot and held in position. When the rimming action has ceased the level of steel drops by several centimetres and the top is watered with between 50 and 200 litres. Full details of the amounts of Al used and of the results obtained are given.—B. G. B.

The Effect of Oxygen on the Quality of Rimming Steels. I. Procházková. (*Hutník*, 1958, **8**, (2), 51–53). [In Czech]. The effect of FeO content, pouring rate and other variables on the yield per ingot of rimming steel is discussed. The maintenance of a correct oxygen content through control of the process variables, particularly in the deoxidation stage are shown to be necessary for high yields.—P. F.

Continuous Casting of Steel in the USSR. M. S. Boichenko, V. S. Rutes, D. P. Evteev, and B. N. Katomin. (*JISI*, 1959, **191**, Feb., 109–121). [This issue].

Continuous Casting at Barrow. I. M. D. Halliday. (*JISI*, 1959, **191**, Feb., 121–163). [This issue].

PRODUCTION OF FERRO-ALLOYS

Manufacture in India of Ferro-Alloys Used in Alloy Steel Industry. B. R. Nijhawan and P. K. Gupte. (*Nat. Metallurgical Lab., Council of Sci. & Ind. Res. Jamshedpur*, 1958, 116–129). Fe–Mn, Fe–Cr, Fe–Si, Fe–W, Fe–V, Fe–P, Fe–Ti and FeCe production is briefly outlined.

Exothermic Ferromanganese. W. R. Lewis, R. L. Kimberly, T. V. Wainwright and W. A. Olsen. (*J. Metals*, 1958, **10**, Sept., 611–614). An account of the production of exothermic ferromanganese and operating results from its use as a ladle addition at several works.

Ferromanganese: The Spice of Steel. Latest Type of Smelting Plant at New Industrial Centre in Natal. (*Eng. Foundryman*, 1958, **23**, July, 35–37). Plans for a new installation with Elkem furnaces of covered rotating type are described.

Outlook for the Use of Low-Grade Manganese Ores for the Production of Ferromanganese and Silicomanganese. E. M. Alekseev. (*Stal'*, 1958, (7), 617–620).

Smelting Ferromanganese from Low-Grade Manganese Ores. A. Frolov. (*Stal'*, 1958, (7) 620–621).

Production of Ferromolybdenum by the Alumino-Silicothermal Process. Z. Kulinski and B. Paczula. (*Prace Inst. Hutn.*, 1958, (3), 143–145). It is difficult to keep Si low in reducing Mo oxide with Si. It is now found that a mixture of ferrosilicon and Al makes this possible.

FOUNDRY PRACTICE

What to See at Newcastle. C. A. Parsons & Co. Ltd., E. Jopling & Sons Ltd., Hawthorn Leslie (Engineers) Ltd., Clarke Chapman & Co. Ltd., Noble & Lund Ltd., Victor Products (Wallsend) Ltd., Charles W. Taylor & Son Ltd., Jarrow Metal Industries Ltd., North Eastern Marine Engineering Co. Ltd., Armstrong Whitworth (Metal Industries) Ltd. (*Foundry Trade J.*, 1958, **105,** Sept. 25, 371–385). Brief accounts of N.E. Coast foundries are given.

Investigations on the Manufacture of Nodular Graphite Cast Iron by Injecting a Mixture of Calcium Carbide and Magnesium into the Melt. H. Abrecht and K. Giesen. (*Giesserei*, 1958, **45,** Feb. 27, 113–117). A powdered mixture of CaC_2 and Mg was injected into the melt by means of a current of N_2, through a graphite tube immersed in the metal. The CaC_2 had the effect of damping the violent Mg reaction, and the N_2 removed suspended reaction products from the bath. The procedure, metallurgy and costs of the process are discussed.—L. D. H.

Some Structural Considerations in Nodular Iron. V. Pulsifer. (*Mod. Castings*, 1958, **33,** Mar., 46–48). Metallographic observations on rapidly chilled iron shot are described and interpreted to mean that the nodules of graphite form near the liquidus in a normal nucleation process. A diagram is given to explain the mechanism and the structure resulting from the formation of MgS in nodular iron.—B. C. W.

Erratum

J.I.S.I., **189,** June, p. 183*a*, line 6 from bottom and p. 183*b*, line 3. For Manganese read Magnesium.

Promoting the Stable Eutectic Reaction in Magnesium-treated Iron Castings by Vibration during Solidification. J. H. Gittus. (*Nature*, 1958, **181,** Apr. 5, 1004–1005). A letter. Castings free from carbide have been produced from Mg-treated iron with $< 0{\cdot}2\%$ Si by vibration at 100 cycles/sec and an amplitude of 0·04 in.

Use of Nodular Graphite Iron in the Construction of Agricultural Machinery. C. Stefănescu, V. Vines and L. Sofroni. (*Acad. Romîne Met.*, 1957, **2,** (3), 321–336). Replacement of malleable by nodular iron castings is described. In one set of trials the use of Mg with various heat treatments was studied in crucibles and in a second set, semi-industrial conditions were used in the forehearth of a cupola.

Nodular Cast Iron Piston Rings with a Ferritic Matrix. T. Dumitrescu and P. Popescu. (*Rev. Mét. Bucarest*, 1957, (2), 83–90). [In English]. Composition and structure, working conditions, cylinder wear and other factors are investigated. The advantages of ferritic nodular iron using only Si as alloying element are stated.

Investigation on Cast Iron Having Refined Graphite Produced by Melting Cast Iron Covered with Slag Containing TiO_2. VIII. Influence of Addition of Metallic Titanium, Ferro-titanium and Cu–Ti alloy upon the Structure of Grey Cast Iron. H. Sawamura and M. Tsuda. (*Tetsu-to-Hagane*, 1957, **43,** Nov., 1234–1242). Grey cast irons containing amounts of Ti up to and more than 0·05% as TiC were prepared from melts containing 3·5% C and 1·8% Si cast in small moulds. It is not certain that the same result would be found with large moulds. **IX. Investigation on the Net Structure and the Estimation of Micro-Hardness of S-H Cast Iron.** (Dec., 1286–1292). The fracture surface as well as the polished surface of S-H cast iron has a net structure; the boundary lines are composed of austenite dendrites and the mesh of eutectic graphite. The good wear-resistance of S-H iron is attributed to the net structure, in which the boundary lines have a higher micro-hardness than the mesh, and the fine, uniform distribution of TiC particles. (13 references).—K. E. J.

The Dilution of Molten Nodular Grey Iron during the Casting of Rolls. B. Körös. (*Koh. Lapok*, 1957, **12,** Apr.-May, Öntöde 97–98). The author critically comments on a Russian roll casting method, which consists of the dilution of a small amount of Mg-inoculated molten grey iron into a larger quantity of ordinary molten grey iron.—P. K.

The Production of Malleable Cast Iron in Scandinavian Countries. W. Sakwa. (*Prz. Odlew.*, 1958, **8,** (4), 110–112).

Researches on the Technique of Casting Malleable Cast Iron. M. Bednářík. (*Slévárenství*, 1958, **6,** (2), 15–22). [In Czech]. Experimental castings were used to study shrinkage, the use of chills and the optimum design and effectiveness of risers on castings varying appreciably in size; typical dimensions being 0·7 × 2·2 × 10 inches. The composition of the white cast iron, which was intended for conversion to ferritic malleable iron, was 2·23–2·49%C, 1·15–1·29%Si, 0·33%Mn, 0·1%P, 0·19%P.—P. F.

Improving the Technology of Preparing Malleable Cast Iron and Reducing Rejects, by Inoculation with Metallic Bismuth. S. Scadowski and M. Avram. (*Met. Constr. Masini*, 1958, **10,** (1), 12–16). The investigation shows that it is possible completely to eliminate the mottled structure of large castings, to work with one charge for thin and large castings, to prevent rejects in cases of errors in overstepping the limit of C and Si, to cast pieces with walls approximately twice as thick as would be possible with iron free from bismuth and to increase appreciably the limits of C plus Si. This results in an appreciable increase in the fluidity of the castings without the necessity for overheating, and in the reduction of the cycle of malleabilization in the first and second stages of graphitization, which makes it possible to use malleable iron in cupolas.—L. H.

Low Alloy Steel 18 DGS–L for Shaped Castings for Hydraulic Machinery. I. R. Kryanin and G. I. Babushkina. (*Metallov. Obra. Met.*, 1955, (2), 28–32). The experiments investigated the effect of Cu additions between 0·2 and 2·75% to the existing types of steel and were carried out in the laboratory in high-frequency furnaces and in arc furnaces of 700 kg. capacity. The castings were subjected to thermal treatment; annealing at 900°, normalizing at 880° and tempering between 580° and 600° with cooling in the furnace. The new type of steel evolved with 1·2%–1·5%Cu and 0·14%C has been named as in the heading. It has proved superior, for the special purposes for which it has been evolved, to the older types of steel. Full results of tests are recorded.—L. H.

Determination of Feeding Sections For Sand Castings. C. Trenckle. (*Fond. Belge*, 1958, **28,** Feb., 61–62). A summary of the non-mathematical sections of a paper presented to the 30th Congress of the Association Technique de Fonderie in Paris, June 1957. The aspects dealt with include the factors affecting pouring times and the flow of metal through the feeders.—B. C. W.

Factors Affecting the Surface Finish of Steel Castings. D. V. Atterton. (*Foundry*, 1958, **86,** Jan., 78–83; Feb., 107–111; Mar., 92–95). Research into the problem of burnt-on sand is critically reviewed with particular reference to the factors affecting the magnitude and extent of the defect. The aspects considered include the measurement of metal-mould interface temperature, the surface tension of molten metals, the contact angle between metal and sand, the effective pore radius of the sand, the effects of sand ramming, the gas atmosphere in the sand pores and the influence of mould and core washes. In conclusion the surface finish produced by various moulding techniques is discussed. (29 references).—B. C. W.

The Preparation of Moulding Sands. L. Demeter. (*Koh. Lapok*, 1957, **12,** Apr.-May, Öntöde, 73–81). Suggestions are made for the correct preparation of Hungarian natural moulding sands for satisfying the requirements of the foundries.—P. K.

Effect of Grain Size on Physical Properties of Synthetic Moulding Sand. C. E. Schubert. (*Foundry*, 1958, **86,** Mar., 88–91). Data on the effects of sand grain-size on green permeability, and the green and dry compressive strength of synthetic silica sands are presented and discussed.—B. C. W.

Some Remarks on the Ramming of Sand Specimens. F. Varga and P. Németh. (*Koh. Lapok*, 1957, **12,** Jan.-Feb., Öntöde 34–37). The authors compared the Hungarian (MNOSZ), German (DIN) and British (AFS/BS) standard specifications for gas permeability and strength of moulding sands, and found that the Hungarian and German standards specify a higher strength and lower permeability, than the British.—P. K.

The Preparation of Foundry Sands in Modern Mechanized Plants. G. Somigli. (*Fonderia Ital.*, 1958, **7,** Jan., 2–6). [In Italian]. A review is given of modern foundry practice with particular emphasis on the preparation and treatment of normal and synthetic foundry sands.—M. D. J. B.

VACUUM METALLURGY

Resistance Heated Vacuum Furnaces. (*Wild-Barfield J.*, 1958, **6,** Sept., 2–7). Furnaces are classified and briefly described and the pumping systems are also schematically shown.

Vacuum Melting and Heat Treating. R. Giler. (*Ind. Heat.*, 1958, **25,** March, 480–494, 626). Vacuum equipment and measuring gauges are reviewed. For heating, induction or electric arc furnaces are employed with a growing preference for the latter.—A. G.

High Temperature Furnace Speeds Vacuum Heat Treat. (*Iron Age*, 1958, **182,** July 31, 58–59; *Steel*, 1958, **143,** July 21, 126, 129). A new furnace is described capable of temperatures above 3000° F and a vacuum of 0·1 micron. Features include a new type heating element, rapid heating and cooling rates and close control.—A. G.

REHEATING FURNACES AND SOAKING PITS

Soaking Pit Utilization. B. Fazan. (*Centre Doc. Sidér. Circ.*, 1958, (4), 835–851). The results of a comprehensive survey of soaking pit practice are discussed. Data from 15 works in France are used and this covers old and new pits and basic Bessemer and O.H. ingots.—B. G. B.

Vacuum and Protective Atmosphere Furnaces for Modern Materials. E. Zeitz. (*Elektrowärme*, 1958, **17,** Sept., 324–325). Types of furnace are briefly classified according to heating element and purpose: (heating, melting or sintering). Degussa equipment is illustrated.

Induction Heating of Rough Forgings. (*Usine Nouv.*, 1958, **14,** May 15, 35). A short description of the types of furnace used, choice of frequency, operation and advantages and disadvantages of the induction heating of half-finished forgings.

Ingot Surface-Temperature Measurement in Forging Furnaces. J. R. Pattison. (*JISI*, 1959, **191,** Feb., 163–171). [This issue].

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Principles of Furnace Design, I, II. (*Esso Oilways*, 1958, **9,** (4), 17–19; (5), 15–17). The articles refer mainly to boilers but some industrial furnace designs are considered.

Heat-Treatment of Mark 18XET Steel Using Hardening Carburization. K. A. Kashchenko. (*Vestnik Machin.*, 1954, (9), 62–65). Experiments were carried out on the cementation of steel bits in a half-cone carburizator with subsequent quenching and annealing. The best mechanical properties

of steel were obtained by a double quench, followed by annealing. The depth of the layer of cementation was about 2·5 mm, it consisted of cementite and gradually passed into sorbite-like pearlite with a ferrite matrix.

Cementation in a Molten Cast Iron. A. N. Rozanov. (*Vestnik Machin.*, 1954, (11), 60–61). A new rapid method of cementation for solid cast iron is proposed, in which the carburizer is a liquid cast iron with 3·5% C and 2% Si. Samples of cast iron are placed in the liquid cast iron at a temperature at about 1300° C and kept on for from a few sec to 3 min and over. The depth of zones depended on the length of treatment. On immediate quenching or delayed quenching it was found that the cementite zone exhibited a high degree of hardness.—S. I. T.

Spark Plus Arc Harden Steel in Russia. I. I. Kichkin. (*Metalw. Prod.*, 1958, **102**, Jan. 3, 3–5; from *Vestnik Maschin.* 1956, **36**, (5), 65–68). A surface hardening method and its uses are described. An account of the apparatus is given.

Action of Activating Additives to Solid Carburising Materials for Steel. P. Wincierz. (*V.D.I.Z.*, 1958, **100**, Jan. 1, 21–22). Information concerning the effect of Ba and Ca oxides, carbonates, and chlorides on the cementation rate of charcoal is summarized.

How Hardening Media Function. (*Aciers Fins Spéc.*, 1958, March, 88–93). Variables in hardening due to the cooling medium, the nature of the piece and the type of process are discussed. Factors governing the choice of process and the selection of a hardening liquid are considered.—A. G.

Synthol, the New Practical Carburiser for Gaseous Cementation. A. T. Kalinin, M. N. Kunyavskii and A. Ya. Zaitseva. (*Metall. Obra. Met.*, 1956,(11) 40–49). Cementation of various steels with the use of Synthol (petroleum) fractions between 100–230°, 100–320° and 200–320° have been carried out under various conditions. Results give a favourable comparison between Synthol and kerosene, as the former forms only one-half to one-third of the soot made by kerosene and gives 1·5 to twice the volume of gases. Synthol increases the rate of cementation in furnaces by 25–30% besides offering also other advantages.—L. H.

Methods of Avoiding Cracks During the Cementation of Parts of Chromium–Nickel Steel. A. M. Nakhimov. (*Vesnik Machin.*, 1955, (3), 74–75). Observation shows that cracks formed in the cementation layer can be avoided by slow cooling, say during 36 h. Annealing at 650° after cementation also prevented the formation of cracks. Dilatometric curves are shown to be useful for the estimation of the safe process of cementation.

Defects of Cementation with a Solid Carburizer. A. M. Tarasov and B. A. Stetsenko. (*Vestnik Machin.*, 1955, (3), 70–73). The defects of a solid carburizer are high cost of labour and fuel among others. The present study shows an important defect related to the supersaturation with carbon of the cementation zone, and details of this study are presented. This defect can only be avoided by the use of a gaseous carburizer.—S. I. T.

Sprue Spreader and Sprue Bushing Design. F. Halward. (*Precision Met. Mold.*, 1957, **15**, Mar., 49–52). The design, hardening and heat-treatment of an air-hardening steel sprue spreader is described.

Carburizing of Steel: Methods, Properties and Applications. A. G. Gardner. (*Mech. World*, 1958, **138**, May, 201–205). A review of pack, gas and liquid carburizing, with selection of steels, furnaces and uses is presented.

Recarburization of Molten Iron in a High Speed Rotary Vessel. R. I. Higgins and J. C. Billington. (*B.C.I.R.A. J. Res. Dev.*, 1957, **7**, Dec., 95–109). The results of small scale tests to measure the rate of recarburization of molten iron by dissolving coke breeze are described.—B. G. B.

Cooling Media for Electro-Hardening of Steel. Yu. M. Bogatyrev and V. P. Pleshachkova. (*Metall. Obra. Met.*, 1956, (11), 54–63). Emulsions are suitable for a slow rate of cooling, (from the temperature of pearlite transformation and above), for the martensite transformation. Solutions of glycerol and $KMnO_4$ are effective for hardening steels for which the martensite point is below 300°. from an economic point of view, it must be born in mind that a 5% Solution of $KMnO_4$ is 30% cheaper than a solution of glycerol in water.—L. H.

Flame Hardening. G. Meredith. (*Met. Treatment*, 1958, **25**, Apr., 151–156). Control of depth of hardness and uses and equipment are discussed. Either the workpiece or the burner and jets may be stationary or both may move. In consecutive hardening the work revolves heated by a stationary burner which is then removed and the quenching spray applied. Applications are then shown and uses for carbon steels, alloy steels, steel castings and cast iron are surveyed.

Isothermal Hardening of High Strength Cast Iron with Spherical Graphite. V. I. Prosvirin and N. A. Patrina. (*Metallov. Obra. Met.*, 1955, (2), 42–50). The isothermal treatment can be used for improving the qualities of high-resistance cast irons, which are lowered owing to graphitic inclusions. The study was carried out to investigate the changes in hardness as a function of the temperature of hardening and of its duration, and the influence of isothermal hardening on the resistance in use, such as resistance to abrasion, to cracks and to fatigue.—L. H.

Induction Heating at Radio-Frequency. F. Viart. (*Publ. Assoc. Ing. Faculté Polytechn. Mons*, 1958, (1), 19–31). Theoretical considerations governing the choice and use of radio-frequency induction heating are dealt with, introduced by a discussion of the general theory of induction. A later paper will give practical applications of radiofrequency induction heating.—L. D. H.

Influence of the Parameters of Induction Heating on the Size of Austenite Grains in Carbon Steels. I. N. Kidin. (*Metall. Obra. Met.*, 1956, (1), 40–41). Experimental results show that in this case (steel type Y10 heated to 840–880–920–960° and 1000°) an increase in the non-uniformity of the carbon concentration in the martensite crystals effectively increases the hardness 2–4 times more than does a decrease in the size of the grains of the original austenite. An increase in the temperature from 840–1000° does not result in a reduction of hardness although the size of the austenite grains increase from 9 to 17·2 μ.

Radio-frequency Induction Heaters. R. P. P. Ellis. (*Met. Treatment*, 1958, **25**, Apr., 145–147, 156). Advantages are listed and the development of heat in the workpiece is reviewed. Generator operation, depth of penetration and effects of the Curie point are considered and choice of frequency is explained. The high cost of the method limits its applications.

Induction Hardening Large Rolls. (*Metalw. Prod.*, 1958, **102**, May 9, 839). New equipment built by Birlec Ltd. is briefly described.

Control of the Thermal Treatment of Steel Parts by the Magnetic Permeability of the Areas of Interior Fields. A. M. El'gard and S. K. Ginzburg. (*Zavods. Lab.*, 1958, **24**, (1), 96–101). By means of a special induction apparatus provided with a transformer, a full description of which is included, different types of steel were investigated, especially regarding hardness as a function of thermal treatment. This method makes it possible to control re-heating below 600° since in tempering high speed steels, hardness diminishes and magnetic permeability increases. This method can also be used for the determination of the content of residual austenite in steels.—L. H.

Influence of the Preliminary Thermal Treatment on the Brittle-Resisting Nitrided Layer of Steel 38 KhMYuA. N. A. Fertig. (*Metallov. Obra. Met.*, 1955, (1), 57–61). It has been shown that the lowering of the temperature of hardening from 950 to 900° ensures a higher brittle-resisting nitrided layer with completely satisfactory mechanical properties of the core and uniform tempering. Induction heating with high frequency currents can be used with advantage for improving the original structure and increasing the brittle-resistance of the nitrided layer.—L. H.

FORGING, STAMPING, DRAWING, AND PRESSING

Drop Forgings to Suit the Final Machining. O. Kienzle. (*Met. Treatment*, 1958, **25**, Aug., 315–321). Components are classified according to whether the forged surfaces require no machining, require only rough grinding or require machining. For the third group material quality, hardness and uniformity, and dimensional limits need to be taken into account. These factors, particularly deviations from shape, are discussed and related to the needs of turning, boring, milling and broaching. The special effects of cold pressing and the precision attainable are then reviewed.

Segration and Internal Weakness in Forging Ingots. N. H. Bacon. (*Nat. Metallurgical Lab., Council of Sci. & Ind. Res., Jamshedpur*, 1958, 225–235). Trials on the mechanism and prevention of 'A' segregation are reported. It appears that the impurities pushed forward by the advancing wall of solidification reduce the freezing to a point at which solidification occurs on the inner side, thus entrapping the zone; evidence for this mechanism is produced. Corner segregation is then considered and its correction by mould design explained. Basal cone weakness is then surveyed, in which cavities are opened up below the 'V' segregation areas by forging. Again ingot mould design, where freezing occurs from the bottom, is a remedy.

The Application of Remote Position Control to Forges. L. J. Chant and F. Seredynski. (*JISI*, 1959, **191**, Feb., 185–188). [This issue].

Western Electric's Modern Metal Finishing Plant. A. W. Cagle and E. J. St. Amand. (*Met. Fin.*, 1958, **56**, Aug., 48–52). An illustrated account of service, ventilation, acid-proof coatings and dryer installations is given.

400-Ton Press Performs Versatile Draw Jobs on Furnace Components. W. Lindbeck. (*Western Metalw.*, 1958, **16**, Aug., 39). A brief description of a press drawing heat exchanger shells, 7-in. tubes (with a 4 ft stroke) and combustion chambers for furnaces is given.

Developments in the Feeding of Power Presses. J. D. Udal. (*Sheet Metal Ind.*, 1958, **35**, Aug., 603–610, 622). Recent improvements in the feeding of strip and coil stock and of individual components for power presses are discussed and a number of examples quoted. The benefits, increase in output and higher safety factors, of inclusion of automatic component and scrap ejection on all press tools are pointed out.—T. G.

Investigations on Some Problems of Deep-Drawing. Part II. H. Beisswänger and S. Schwandt. (*Forsch. Wirts. Nordrhein-Westfalen*, 1954, No. 117, pp. 77). A testing machine and results on a number of materials are described.

Research into Deep Drawing. G. Murray. (*Sheet Metal Ind.*, 1958, **35**, Sept., 657–675). A review of the process analysing metal deformation and flow processes, and the assessment of drawing properties, simulative ductility tests, (cup stretching, hole widening, wedge-drawing, cup-drawing and bend tests), other measurements of ductility, tensile testing and its interpretation, elongation values and the hydraulic bulge test and work-hardenability studies are given.

Strengthening Carbon Steel Wire Made from Patented Billets. K. D. Potemkin. (*Stal'*, 1958, (7), 654–659). The tensile strength of wire made from patented billets increases with carbon content, billet diameter, individual and total reductions. A variation of 0·1% in the carbon content has the same effect on the tensile strength as a variation of 4 mm in diameter or changes of 10% in reduction. A formula is developed for calculating the increase in the tensile strength of wire and it can be used in selecting the carbon content and the distribution of the amounts of drafting.—B. S.

Adsorption Plastification of the Surface Layer by Lubricants in Pressure Working of Metals. S. Ya. Veiler, V. I. Likhtman and P. A. Rebinder. (*Doklady A. N.*, 1957, **116**, (3), 415–418). Experiments were made in

drawing a steel wire coated with copper, and also aluminium strip, and to study the influence of various lubricants on the "effective coefficient of friction" and on the applied force. The effect of liquid lubricants in pressure working of metals, it is shown, is determined by the properties of the fine surface layer of the metal, resulting from adsorption plastification.—S. I. T.

ROLLING MILL PRACTICE

Remote Position Control of Screwdown Drives of Primary Rolling Mills. L. N. Bramley, F. Seredynski, L. J. Chant, and G. K. Steel. (*JISI*, 1959, **191**, Feb., 176–185). [This issue].

A Simplified Nomograph for Determining the Radius of the Deformed Part of a Roll in the Cold Rolling of Strip and Sheet. D. Ya. Gurevich. (*Stal'*, 1958, (7), 635–638).

Card Programming on An Automatic Reversing Mill. E. H. Browning. (*Blast Furn. Steel Plant*, 1958, **46**, Mar., 299–302). The automatic control of a reversing roughing mill at the Aliquippa Works of Jones and Laughlin Steel Corporation is described. The Prodac card-programmed digital computor controls the operation.—B. G. B.

Up-to-date Roll Design. Grooving of Rolls for Structural Sections and Broad Strip. J. Mercader. (*Koh. Lapok*, 1957, **12**, Apr.-May, 150–156). The author reviews the principles of up-to-date roll design.—P. K.

New Bar Mill: Double Duo Installation Opened at Sanderson's. (*Iron Steel*, 1958, **31**, Feb., 53–55). A new 10½ in. bar mill has recently been installed by Sanderson Bros. & Newbould Ltd., Sheffield. It is a five-stand double-duo type and will be used for rolling high-speed, tool and alloy steel bars to close dimensional tolerances. Details are given of the design of the mill, its electrical equipment, and the mill ancillaries.—G. F.

Rational Pass Design for Rolling Hexagons. A. Nefedov and B. M. Ilyukovich. (*Metallurg*, 1958, (3), 22–24). Four pass designs for rolling hexagons are compared.—R. S.

Rolls and Rolling. Sheet Piling. E. E. Brayshaw. (*Blast Furn. Steel Plant*, 1958, **46**, Mar., 310–312, 337, 339, 341, 345–348). A detailed review of roll pass design and mill operation for rolling sheet piling is presented.

Rationalisation of Rail Pass Design. B. S. Shapiro. (*Stal'*, 1958, (3), 227–230). Elimination of edging passes, use of a thick initial bloom, use of a high knife in the first diamond pass and oblique positioning of the rail-forming grooves with limited spread are found to be advantageous.—R. S.

Method of Solving Rail Production Problems. D. S. Kazarnovskii. (*Stal'*, 1958, (2), 138–144). It is claimed that a thorough study of the surface hardening of rail heads is required along the entire length of the rail and treating each rail separately. Rails for curved sections should be made in alloy steel. Normalizing of Bessemer rails should be introduced and the carbon should be raised to 0·75%. Stresses in cold-straightening should be reduced, more 25 m lengths should be made, the best ingot weight is not established and a better form of rail should be worked out for the 50 km/m quality and the radii of the curved face should be improved. Track planning should be improved with reduction of number of curves and increase of radius. Other track details are also considered.—R. S.

A Remarkable Defect in the Rolling of Rails. B. I. Božic. (*Documenta Chemica Yugoslavica*, 1957, **22**, (3), 187–192). Bulging of the neck of the rail was observed in some cases during cooling and this was traced to the tipping of the ingot before it was completely solidified. Allowing longer cooling time corrected the fault.

Experience with the Work of the Best Inspectors of the Technical Control Department of the Azovstal' Works. V. V. Trofimov. (*Metallurg*, 1956, (6), 26–28). Organization of work of an inspection team for the control of the quality of railway rails is described.—V. G.

Modernising a Sheet Mill. A. P. Koshka and V. A. Brusilovskii. (*Metallurg*, 1958, (3), 27–28). The article describes the modernization of an existing sheet mill, including the enlarging of the descaling tanks, increase in the speed of descaling and coiling, improvements in the radial bearings and in the oiling of the strip.—R. S.

Alloy Steel Sheets and Strip. (*A.I.S.I. Steel Prod. Man.*, 1958, Apr., pp. 37). Metallurgy, manufacturing practice, quality descriptions and tests, tolerances, compositions, sampling and analysis are reviewed.

Smoothing Pass Walls in a Working Stand. I. T. Lyzhenko. (*Metallurg*, 1957, (12), 30). A simple device for smoothing walls of roll passes is briefly described. It consists essentially of a holder to keep pieces of an emery wheel in contact with the walls while the roll is rotated.—S. K.

Rolling- and Recrystallisation Texture of an Iron–Nickel Alloy with 30% Ni. J. Grewen, A. Segmüller and G. Wassermann. (*Arch. Eisenhütt.*, 1958, **29**, Feb., 119–124). The rolling- and recrystallization textures of a metal sheet reduced by more than 95% have been investigated. Results are presented in quantitative diagrams.—L. J. L.

Experience in Operating a 2800 mm Plate Mill. D. I. Timofeev. (*Metallurg*, 1957, (1), 24–26). A description of the mill and the operating practice used is given.—V. G.

The Future of Plate Rolling in the Danube Iron and Steel Works. F. Arkos and L. Kismarty. (*Koh. Lapok*, 1957, **12**, Aug.-Sept., 414–419). A comprehensive review is given of the present and future production of steel plate, sheet and strip in Europe. Using these data as a basis, comments are made on the future of the plate, sheet and strip production planned in the Danube Iron and Steel Works in Hungary.—P. K.

Experience with the Production of Composite or Clad Sheets. V. A. Filonov, A. A. Podgorodetskii, F. A. Ksenzuk and V. N. Lola. (*Stal'*, 1958, (2), 188–191). Two-layer ingots and slabs up to 12½ t are produced. Careful preparation of the stainless steel surface is necessary before filling with liquid carbon steel. The stainless was cast into moulds with a top cross-section 640 × 1350 mm and a bottom cross section 590 × 1310 mm, 1850 mm high. Analyses are given. The ingots were heated in soaking pits 5 h 35 min at 780° and brought up to 1200° in 6 h. They were turned through 180° to effect uniform heating and malleablized for 2½ h with a wall temperature of 1220–1230° and rolled to slabs 560–500 mm thick and then reheated for 1½–2 h at a wall temperature of 1250–1260°. They were then reduced to 100 × 1280 mm and cut into slabs 1800–1850 mm long. Maximum reduction per pass did not exceed 20 mm.—R. S.

Establishing an Industry Standard for the Variation in Weight of Carbon Steel Sheets. D. H. W. Allan. (*Reg. Tech. Meet. A.I.S.I.*, 1957, 627–636). A survey by the Institute is reported.

The Present State of Transformer Sheet Production and Development. G. Rassmann. (*Neue Hütte*, 1958, **3**, April, 193–203). The magnetic properties of hot rolled sheet can be improved by using higher temperatures in the final heat treatment. In cold-rolled sheet, the formation of texture is determined by the state of the metal, particularly by the carbon and nitrogen compounds. The rapid progress of decarbonization in hydrogen permits the use of continuous-heating furnaces.—L. J. L.

[Jones & Laughlin] Starts Operation of 44-in. Mill at Aliquippa. (*Iron Steel Eng.*, 1958, **35**, Feb., 164–165, 169, 170). This new 55-in. semi-continuous hot strip mill is the first to have a fully automatic programmed control system on the reversing rougher. It will roll over 100,000 t of coiled strip (up to 40 in. wide) per month, for pipe and tinplate manufacture.—K. E. J.

Punch Cards Program Rolling Mill. (*Iron Age*, 1958, **181**, Feb. 20, 92–93). The operation of a new card programming system which controls a 44 in. hot strip rolling mill at Jones & Laughlin Steel Corp. is described. Punched cards are fed to the 'card reader' which controls the mill screwdown opening, edger adjustment opening, mill speed, and edger speed. Various instruments on the plant also feed information during operation.

Layout and Operation of a Modern Continuous Rolling Mill for Medium Strip. H. Severing. (**Stahl u. Eisen*, 1958, **78**, Feb. 20, 205–214). The modernization of the medium-strip mill of Hoesch Walzwerke AG, Hohenlimburg, was started in 1953. Layout, construction, auxiliary plant, and the operation of the mill are described. The mill has 18 stands in tandem, the first are two high, the last five four high, six of the stands are vertical. Thickness and width variations of the finished strip are particularly low.—T. G.

The Continuous Rolling Mill for Medium Strip of Th. Wuppermann GmbH, Leverkusen. H. Lampmann. (**Stahl u. Eisen*, 1958, **78**, Feb. 6, 160–167). A seven-stand, four-high, tandem hot rolling mill for strip up to 700 mm wide is described. The present output is about 50 t/h: after installation of another soaking pit it will be increased to 100 t/h. By employing 7 stands instead of the usual 6 the variation in thickness of the strip is markedly reduced.—T. G.

Modern Methods of Producing Flat Rolled Products. G. A. Jedenoff. (*Reg. Tech. Meet. A.I.S.I.*, 1957, 535–566). Classification, integrated production facilities, control and finishing processes are reviewed with many illustrations.

MACHINERY AND SERVICES FOR IRON AND STEEL PLANT

Structural Design Problems and Recommended Practice for Ore Bridges and Unloaders. W. B. McLean. (*Iron Steel Eng.*, 1958, **35**, Aug., 78–86). Design problems in the loading, allowable unit stresses, type of construction, design of details, materials used and mechanical properties of ore bridges are discussed in the light of American specifications and recommendations.—L. D. H.

Iron and Steel Handling with Lifting Magnets. C. C. Richards. (*Mech. Handling*, 1958, **45**, Oct., 654–658).

Sulzer Gas Turbines for Steelworks. (*Wiggin Nickel Alloys*, (49), 3–7). An illustrated account.

"It Ain't Mechanical." J. L. Lindberg. (*Iron Steel Eng.*, 1958, **35**, Sept., 166–172). The organization of the mechanical department of the Pueblo plant of the Colorado Fuel and Iron Corporation is described and illustrated by examples.

Protection Against Prolonged Delays on Main Drive Electrical Equipment. H. H. Angel. (*Iron Steel Eng.*, 1958, **35**, April, 77–84). The paper discusses the need for carrying major spare parts and complete spare units in the electrical departments of a large integrated works. Practice at Bethlehem Steel Co. is described.—M. D. J. B.

Standardized Component Parts for Heavy Duty Mill Type Cranes. M. R. Bowerman and E. R. Madison. (*Iron Steel Eng.*, 1958, **35**, July, 104–111). The results of research carried out on the standardization of crane components are described and discussed. It is pointed out that cranes can be built more cheaply and replacement of parts is simplified. Standardization was carried out on the trolley drive and hoist installation.

Stocking Out Stainless Steel Tubes. K. Mumby. (*Mech. Handling*, 1958, **45**, Sept., 597–601). Use of a side-loading fork truck and a portable rack system at Walsall is described and illustrated. The racking is of all-welded steel giving 5-tier stacking at 2 ft vertical pitch.

The Water Economy of the Hoesch-Westfalenhütte A.G., Dortmund. M. Zur. (*Stahl Eisen*, 1958, **78**, Aug. 21, 1191–1200). The total water consumption of the works is about 33,000 m³/hr. All the water is re-circulated and treated before re-use. Plant and equipment for the treating of the water is described and the costs discussed. The purchase of mains water could thus be reduced to about 650,000 m³/month. For emergencies, Diesel engines for pumping the re-circulated water are to be preferred to storage tanks.—T. G.

WELDING AND FLAME-CUTTING

Conference on Welding Engineering. (*U.S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia, April*

29–*May* 1, 1957). **Factors in the Selection of Welding Processes.** J. J. Chyle. (9–38). The author reviews the factors which should be considered in the selection of the most suitable welding process taking into account service requirements and engineering design. Close co-operation between designer and welding engineer is emphasized, examples are quoted and welding costs considered. **Research Destructive Test Methods for Weldability.** W. L. Warner. (59–90). The author discusses the problem of the evaluation of weldability from laboratory tests to true weldability and describes the conventional destructive tests and their limitations. **Hard-Facing.** R. T. Phillips. (179–202). The reduction of wear by hard-facing and the benefits gained by hard-facing are shown. Methods of hard-facing and alloys best suited for special purposes together with examples are described. **Surfacing by the Thermo-Spray Process.** S. Tour. (203–212). The powder-spray process using a special gun developed by the Metallizing Engineering Co., Inc., Westbury, is described and the advantages of using powder instead of wire is stressed. Alloy and ceramic powders were developed for special purposes. Examples of application and microstructures of deposits are shown. **Research and Experience in Welded Steel Construction.** LaMotte Grover. (235–243). A number of specific examples of improper applications of results of research and experience with respect to bridge construction is cited and the new ASTM–A373 bridge specification discussed. **The Evaluation of Laboratory Fatigue Studies of Welded Structures.** W. H. Munse. (245–252). The author discusses the extrapolation of fatigue from laboratory to field conditions with respect to welded bridges. Tests and testing equipment are described and *N*/*S* curves obtained shown. **The Use of Steel Castings in Engineering Weldments.** N. N. Breyer. (281–293). The decision of when to use castings or composite structures must be made on the design board so as to take advantage of casting technology. Savings can be effected in the production of composite weldments. Examples are quoted. **Considerations on the Incorporation of Steel Castings in Welded Structures.** S. W. Gearhart, jun. (295–306). For composite structures, simple castings can be used, this is a great advantage when high-quality steel castings are involved. The castings should be designed to make full use of the simplification obtainable, but at the same time for easy and correct welding. A number of examples are described and the savings in costs discussed. **Effect of Welding on the Notch Toughness of a Casualty Material (280 mm Carriage Rear Float Bolster).** W. P. Hatch, jun. and C. E. Hartbower. (361–380). The rear bolster and traversing gear housing of a 280-mm carriage failed during subzero-temperature operations. The failures involved entirely different types of steel and occurred under widely different circumstances. The tests and the results obtained are described. It is recommended that a weldability test for evaluation of the relative toughness of the weld heat-affected zone and base metal should be incorporated in the specifications for steels which are used in critical service applications. **The Fusion Zone as a Major Weldability Concept in Welding of High-Strength Steels.** J. S. Kobler. (381–398). Fusion-zone properties in high-strength steel weld joints are inherently brittle and retain this characteristic in the presence of dilution incompatibility. Fusion-zone properties assume characteristics of the surrounding metal (weld and base metal) in the presence of dilution compatibility. Test procedures and results obtained are described. **Defective Welding in Items Procured by Government Agencies.** H. J. Nichols. (423–437). Bad design and/or poor fabrication methods are the cause of the defective weldments. A number of examples are quoted and illustrated. **Non-Destructive Testing Procedures.** A. Gobus. (447–460). A review is given of all available non-destructive testing methods for weldments and their advantages and disadvantages are discussed. The merits of the Electronic Fluoroscope are stressed.—T. G.

Thermal Treatment of Welded Joints of Stainless Steel. V. V. Chernyshev. (*Vestnik Machin.*, 1954, (8), 83–85). Certain chromium stainless steels have a tendency to develop intergranular chromium carbides leading to subsequent corrosion of the welded joints. Experiments were carried out on thermal treatment of the joints by induction high-frequency and oxy-acetylene hardening, both of which were successful in eliminating the intergranular carbide.—S. I. T.

Manual Arc-Welding of Stainless and Heat-Resisting Steels and Alloys with Fusible Electrodes. (*Aciers Fins Spec.*, 1957, Dec., 106–110). This paper discusses metallurgical considerations which control the choice of electrodes and their coatings. Arc-welding can be used for nearly all metallurgical applications, including modern heat-resisting and stainless steels.—R. P.

Welding ST.4 and SKh. L-1 Steels in an Atmosphere of Carbon Dioxide. N. I. Kakhovskii and A. M. Ponizovtsyev. (*Avtom. Svarka*, 1957, (5), 61–63). Data are provided on the technique of welding St.4 and SKh. L-1 steels in an atmosphere of CO_2. The experiments covered several compositions of wire electrode, their performances being described.—L. D. H.

Submerged Arc Welding Gets Boost. (*Steel*, 1958, April 7, 119). A new type semi-automatic submerged arc welder is described and its advantages are listed.—A. G.

High-Temperature Steels and Alloys and Their Welding. H. Gerbeaux. (*Soud. Techn. Connex.*, 1958, **12**, Jan./Feb., 53–61). This paper gives a general survey of available types of high-temperature steels, their properties and application, and appropriate welding techniques.

Welding Rotors of Austenitic Steels. K. V. Lyubavskii and V. A. Toropov. (*Metal. Obra. Met.*, 1956, (10), 52–56). Results of the investigation confirm that it is practicable to use arc welding for rotors of austenitic steels. The play which appears in welding can be controlled by subsequent layers on the welding seams. The magnitude and character of the transverse shrinkage of the welding seams has been experimentally determined as well as the thermal treatment for the welded rotors.

Automatic Welding of Steel Rolls. V. K. Petrichenko. (*Metallurg*, 1956, (6), 5–9). The methods and equipment used for welding wear-resistant steel on rolls is described. An evaluation of the economy achieved in a number of works using this method is given.—V. G.

How to Work Aluminium-Coated Steel. W. E. Mc Fee. (*Iron Age*, 1958, **181**, Feb. 6, 95–97). The techniques necessary for fabricating Al-coated steel are described. Generally it can be worked by standard equipment, but some precautions and modified procedures are necessary. Welding methods are described.

Application of Welding to the Construction of Stainless Steel Carriages for Railways. M. Thomas. (*Soud. Techn. Connexes*, 1957, **11**, Nov.-Dec., 345–351). The properties of stainless steel, particularly the 18/8 type, render it suitable for the construction of railway carriages, resulting in a saving in weight. Assemblies are spot, seam, arc or double-spot welded. Details of the equipment and inspection methods are given.—R. P.

The Welding of Tool Steels. (*Prat. Soud.*, 1957, **11**, Oct., 146–148). The difficulties encountered in welding tool steels and high-speed tool steels are discussed. A suitable heat-treatment process for these steels is suggested before and after the welding operation.—R. P.

Ways of Increasing the Productivity of Arc Welding by Hand of Acid-Resisting Steels of 18–8 Types. Yu. I. Kazennov, A. N. Krutikov, L. P. Kolosova and P. T. Dmitriev. (*Vestnik Machin.*, 1954, (5), 74–77). [In Russian]. Experiments were carried out on the arc welding of steels using a higher current, a higher weight of electrode coating, a bundle of electrodes, or a three phase arc. The last-named method proved to be the best.

The Selection and Welding of Thick Plate for Nuclear Power Applications. A. S. Ailes and W. I. Pumphrey. (*Weld. Met. Fab.*, 1958, **26**, Feb., 62–66).

Some Remarks on Weldability of Steel. S. Butnicki. (*Hutnik*, 1957, **24**, March, 101–103). [In Polish]. Weldability of steel presents a complicated problem, depending on the quality of the steel and the processes of its production as well as on the kind of construction it is intended for and the technology of welding. Schnadt's experiments in this field are described.

Effects of Some Alloying Elements on Weldability of Low-Alloy Structural Steels. H. Susuki and H. Tamura. (*Tetsu-to-Hagane*, 1958, **44**, Feb., 129–136). [In Japanese]. Ni additions increased tensile strength. Cr improved the mechanical properties in the quenched and tempered condition. Mo increased the tensile and yield strength in the normalized and the quenched and tempered conditions. Effects on the V-notch Charpy value are described. The as-welded max. hardness was greatly increased by Cr or Mo. Allowable stength limits are listed for satisfactory weldability of the steels with additions of the single elements.—K. E. J.

Weldability of Notch-Ductile Steels. L. Reeve. (*Weld. J.*, 1958, **37**, Feb., 74s–80s). Weldability tests are described which have been carried out on a series of C–Mn steels, including a number of notch-ductile steels (BS2762, 1956), CTS and Battelle cracking tests were used. It is shown that results are more in accordance with British carbon equivalent formula than with Battelle formula for weldability.—U. E.

Some Properties of Basic Shielded Electrodes and Their Application. (*Prat. Soud.*, 1957, **11**, Aug.-Sept., 114–121). The reasons for using shielded basic electrodes are discussed with examples of their use in welding.—R. P.

Development of Filler Wires for Welding SAE 4130, 4140 and 4340 Steels. H. W. Mishler, R. P. Sopher and P. J. Rieppel. (*Weld. J.*, 1958, **37**, Feb., 41s–48s). Filler wires were developed for welding high-strength low-alloy aircraft steels by the inert-gas tungsten-arc and inert-gas consumable-electrode processes. Best results were obtained by using filler wires with a composition similar to the base metal.—U. E.

The Use of Fluxes to Promote Welding and Spreading. J. C. Chaston and M. H. Sloboda. (*Brit. Weld. J.*, 1958, **9**, March, 105–107). A new flux has been developed which consists of a mixture of potassium fluosilicate and potassium metaborate and which can be used on copper, brass, mild steel, and other materials.

Electric Furnace Melting of Flux for Automatic Welding. M. M. Timofeev. (*Vestnik Machin.*, 1954, (6), 88–90). [In Russian]. Experiments were carried out on melting Mn-rich fluxes in an industrial furnace of 100 kg capacity at temperatures of 1350–1450°, 1550–1600° and 1700–1750° C. Chemical compositions of the initial charges and their composition during the process of melting and on addition of metal, are given in tables and diagrams. It is concluded that the temperature and time have an important influence on the chemical composition of the final product.—S. I. T.

Welding Fluxes G.D.R. and F.R.G. for Automatic Steel Welding. V. N. Kolisnyk. (*Avtom. Svarka*, 1958, **11**, (1), 22–27). The main classifications are: Fluxes with low Mn content; these are prepared (*a*) by fusion, (*b*) by sintering at high temperature powder and pressed slag-forming components (*c*) by binding powdered materials with sodium silicate solution. Fluxes containing carbon which have high resistance to pore formation. Electrodes with various properties, for example, resistant to formation of pores and heat fissures, having high stabilizing properties, and electrodes with increased Mn and low sulphur content.—L. H.

Equilibrium in Welding between Slag, Metal and Seam. I. I. Frumin. (*Avtom. Svarka*, 1958, **11**, (1), 3–12). Since each portion of metal entering the welding bath is subjected to the same succession of processes, the elementary volume from which the fused-on bead is composed should, in principle, attain a

state of equilibrium. At high temperatures in open arc welding, equilibrium is reached in many cases, at other times only an approach to equilibrium is noticeable. In experimental welding with flux containing over 50% SiO_2, and over 90% SiO_2 plus MnO plus FeO, with different wire electrodes and base metal, from results calculated by a formula proposed by Kramarov?n for acid slags saturated with silicon, it has been shown that at 1700° the composition of metal and slag corresponds to equilibrium in some cases. In the majority of cases however, owing to the rate of cooling of the molten metal, the composition corresponding to a higher temperature has become fixed.—L. H.

Some Problems of Welding with Fluxes, Straight Welded Petroleum Pipes of Large Diameter, Made from High-resistance Steels. S. L. Mandel'berg and O. S. Zabarilo. (*Avtom. Svarka*, 1958, **11**, (1), 56–62). A new welding technique is described which ensures that the metal of the weld and the joint, possess high mechanical properties, and, for certain makes of steel, high resistance to the formation of heat cracks. This technology reduces defects in the welds of pipes, increases the efficiency of the process by reaching 95–100 m/hr for external welds and 80–90 m/hr for internal welds, which represent an increase of 20–25% on the previous rate, and finally reduces the consumption of fluxes by more than 30%.

The Influence of Welds on the Behaviour of Metal Products. P. Roblin. (*Rev. Gen. Méc.*, 1957, **41**, Nov., 105, 475–477). The author discusses the propagation of cracks in welds and the behaviour of welds at low temperatures. The influence of welds on the finished product is shown.—R. P.

A Survey of the Scientific Principle Related to Wetting and Spreading. D. R. Milner. (*Brit. Weld. J.*, 1958, **5**, March, 90–105). The scientific principles underlying wetting and spreading are discussed. The surface tension theory and the thermodynamics of metal oxide reduction in H_2 or CO are considered and free energy data are quoted from the literature. Oxide removal by heating in a vacuum or by using a flux and the effect of surface roughness on bonding the filler metal to the base metal are discussed.—U. E.

The Wetting and Spreading of Liquid Metals on Solid Metal Surfaces. E. C. Rollason. (*Brit. Weld. J.*, 1958, **5**, March, 89–90). Opening address for a conference on this subject held at University of Birmingham, 25th Sept., 1957.—U. E.

Mechanism of the Transformation in the Zone Affected by the Heat of the Arc in the Welding of Steel. F. A. C. Calvo. (*Cien. Tecn. Solda.*, 1958, **8**, Jan.-Feb., 16–34). A paper given at the annual meeting of the Instituto de la Soldadura at Barcelona in October 1957. The article is a detailed survey, illustrated by photomicrographs.

Structure Transformation in Iron During Welding. P. S. Elistratov. (*Metall. Obra. Met.*, 1956, (4), 10–14). The zone susceptible to thermal influences in welded iron consists of those parts which during welding are heated at different temperatures and cooled at various rates and is characterized by different structures. In the first zone, the metal during welding is in a solid-molten condition and during cooling is likely to show cementite formation. In the second zone the metal is in a solid state during welding and on cooling may give rise to excess cementite and also to martensite.—L. H.

Continuous Cooling Transformation Characteristics of Three Types of Weld Metal. E. F. Nippes and E. C. Nelson. (*Weld. J.*, 1958, **37**, Jan., 30s–36s). Continuous cooling transformation diagrams are shown for 180, 230 and 260 type weld metals and differences of behaviour are discussed in terms of alloy content and carbide formation.

Mechanical Properties of the Weld Zones in Steel 55 in Automatic Welding. G. I. Pogodin-Alekseev and M. S. Savel'eva. (*Avtom. Svarka*, 1958, **11**, (1), 37–42). The possibility exists of micro-mechanical investigation for estimating the properties of the various sections of the weld zones, and values are cited, which were determined in respect of these zones for steel 55 having considered the overheating of these zones during the welding operation.—L. H.

Various Methods of Examining Welds. C. Mathy. (*Prat. Soud.*, 1957, **11**, Aug.-Sept., 123–124; Oct., 142–144). Four non-destructive methods of examining welds are briefly described, viz.: radiography, the use of isotopes, ultrasonics and magnetic methods. The theory of the ultrasonic and magnetic methods for examining welds are discussed. The four non-destructive methods examined are complementary to some extent. Their use depends on the type of fault to be detected and on the dimensions of the part to be examined.—R. P.

Results of Fatigue Tests on Butt Welded Joints in Different Countries. R. Cazaud. (*Rev. Soudure*, 1958, **14**, (1), 49–50). Results of fatigue tests on butt-welded joints carried out under similar conditions in various countries gave a wide scatter of results. Investigations showed that conditions under which the tests were carried out and the equipment used varied significantly, as shown in a table giving comparative data.

Secondary Carbides and the Formation of Sigma Phase in the Welded Joints of Stabilised Austenitic Steels of Type 25-30. Yu. B. Malevskii and B. I. Medovar. (*Avtom. Svarka*, 1957, (5), 86–94). The results of an investigation with an electron microscope on welds in austenitic steel, type 25–20 are discussed. Secondary carbides could be distinguished as regular cubes, prisms or parallelopipeds; dendritic carbide was not found. The formation of sigma phase is discussed. (15 references).—L. D. H.

Effect of Preheating and Postheating on Toughness of Weld Metal. T. N. Armstrong and W. L. Warner. (*Weld. J.*, 1958, **37**, Jan., 27s–29s). Seven types of electrode were examined. Postheating weld metal at 1150° F in no case lowered transition temperature and four of the seven showed some degree of embrittlement. Preheating up to 600° F improved the impact properties of E7015 carbon steel weld metal and of E8015-C2 nickel-steel weld metal.

Measurements on the Diffusible Residual and Total Hydrogen Contents of Weld Metal. P. D. Blake. (*Brit. Weld. J.*, 1958, **5**, March, 126–129). Measurements were made of the diffusible H_2 content at 20° C and residual and total H_2 contents under vacuum at 650° C. Data are given of the rate of evolution of H_2 at 20° C from multi-run deposits. The difficulties encountered when measuring the hydrogen contents were investigated.—U. E.

Results of the Fatigue Testing Programme on Butt-Welded Joints in Different Countries. Commission XIII. (*Soud. Techn. Connexes*, 1957, **11**, Nov.-Dec., 386–390). Results are given of fatigue tests on mild steel performed in eight countries. The fatigue limit under 2×10^6 cycles lies between 15 and 30 kg/mm² for the base metal when its strength varies between 40 and 50 kg/mm². If the weld is flush with the base metal these values are 14 and 30 kg/mm², but they fall between 11 and 19 kg/mm² when the weld has not been machined and defects are visible.—R. P.

A High-Speed Dilatometer Designed for Welding Research. E. C. Nelson. (*Weld. J.*, 1958, **37**, Feb., 57s–61s). The design and operation of a high-speed dilatometer capable of duplicating rapid heating rates and high temperatures is described. A continuous cooling transformation diagram for a low-carbon high-alloy steel is reported.—U. E.

Note on the Relief of Welding Stresses on Ship's Hulls and Welded Frameworks. A. Audigé. (*Soud. Techn. Connex.*, 1958, **12**, Jan.-Feb., 31–37). The author discusses the influence of residual stresses in welded ship's hulls, with particular emphasis on brittle fracture phenomena. The results, which can be applied to other welded structures, are related to measures which can be taken to minimize residual stresses by suitable design.—L. D. H.

The Role of Intercrystalline Componens int the Formation of Heat Cracks in Welded Seams. V. A. Toropov. (*Metall. Obra. Met.*, 1956, (4), 45–50). Not only by their quantity, but also by their properties do the intercrystalline components influence the tendency to heat cracks in welded seams. Separation in the metal seams of a carbide eutectic of austenitic structure imparts an increased hardness and resistance and, in spite of low plasticity indices, the metal is not prone to the formation of heat cracks.—L. H.

MACHINING AND MACHINABILITY

The Machinability of Steels. E. Bodart. (*Revue M de la Mechanique*, 1957, **3**, Oct., 125–139). A test is described in which a cylindrical test-piece is turned. Correlations with hardness, structure and with other machinability tests are examined and U.S. steels of various kinds are compared with Belgian. (11 references).

How Steel Firm Checks Machinability. (*Steel*, 1958, **142**, June 23, 108). The research laboratory of the Union Drawn Steel Division, Republic Steel, employs automatic turning machines to shape large numbers of samples. In this way optimum feeds, speeds and tool settings are established.—A. G.

Machinability of Heat-Resisting Stainless Steels. H. Opitz, H. Axer and H. Rohde. (*Forsch. Wirts. Nordrhein-Westfalen*, 1957, No. 385, pp. 73).

A Method for Studying the Behaviour of Cutting Fluids in Wear of Tool Materials. L. V. Colwell. (*Trans. A.S.M.E.*, 1958, **80**, July, 1054–1058). A description is given of a new friction-wear machine, in which normal load can be varied linearly with time and oscillated between preset values; both load and friction reaction are recorded continuously. A description of tests carried out with the machine is given; it has been found possible to discriminate clearly between the effects of different lubricants. The results are discussed.

System Prevents Waste Buildup in Central Coolant Supply. A. B. Myler. (*Iron Age*, 1958, **182**, July 31, 56–57). The system described employs two flotation units which automatically and continuously clarify and recirculate clean cutting oil to 84 machine tools.—A. G.

CLEANING AND PICKLING

Flame Cleaning. (*Corros. Techn.*, 1958, **5**, Sept., 301–302). A brief outline of the technique.

Machine Peels Ingots in In-Line Operation. (*Iron Steel Eng.*, 1958, **35**, Aug., 150, 153). Using the Innocenti peeling machine, ingots are peeled hot, after heating to 2200° F immediately after stripping. Temperature losses are 100–200° F; ingots are returned to the reheating furnace to make good this loss, and are then at a rolling temperature. The machine is made in two sizes, for 3 and 5-t ingots, and it is estimated that 10 ingots an hour can be machined in regular production.

Shot-Blasting in the Shipyard. (*Corros. Techn.*, 1958, **5**, Sept., 285–287). The development and application of a new shot-blasting installation specially designed for use on ship's plates. A special protective coating for application after descaling and before painting has also been developed.

On the Testing and Standardization of Cut-Wire Steel Shot. H. Krautmacher. (*Stahl Eisen*, 1958, **78**, Oct. 16, 1433–1440). Testing equipment is described and illustrated and the laws governing wear and abrasion of the shot are discussed. Cylindrical shot of 0·9 mm dia. and length takes the shape of a globule after about 100 uses; its total lifetime is about 2000. Suggestions for a standard of cut-wire shot including dimensions, hardness, testing equipment and testing procedures are put forward.—T. G.

Electropolishing and Related Techniques. A. A. Tomkins. (*Met. Fin. J.*, 1958, **4**, Aug., 305–312, 316). The general theory of the process is outlined and used of polishing and electromachining are indicated with a note on costs.

Vapour Blasting of Tools. (*Aircraft Prod.*, 1958, **20**, Feb., 61–63). Tests made in Sweden are described. Tools made with and without vapour-blasting were tested on turbine-blade machining and the advantages of the treat-

ment was demonstrated. The tools used were of CRU Excelsior XXVI steel.

Pickle Liquor Disposal Made Practical. (*Steel*, 1958, **143**, July 28, 76–77). Three A. O. Smith plants near Milwaukee pickle 10^6 t of steel per annum and a process has been developed for the disposal of waste liquor. Carbide sludge from an acetylene plant is used for neutralization and produces a by-product suitable for land fill.—A. G.

Electrolytic Recovery of Spent Pickling Solutions. H. Hohn, E. Fitzer and G. Jangg. (*Stahl Eisen*, 1958, **78**, Oct. 16, 1462–1469). A pilot plant for the continuous recovery of iron from sulphuric pickling waste is described. The iron is deposited on horizontal mercury cathodes, the pickling waste enters the cell on one side, the recovered pickling solution leaves the cell on the opposite side for re-circulation. The iron amalgam can be processed in two ways: Ferric sulphate solution is brought into contact with the amalgam, the iron is taken up by the solution and ferrous sulphate is formed that is electrolysed in the usual way, or the amalgam, after a concentration treatment, is heated and decomposed, giving an iron powder that has excellent sintering and working properties.—T. G.

The Advantages of Using Contact Process Sulphuric Acid for the Pickling of Mild Steel. P. G. Kovtun. (*Stal'*, 1958, (7), 651).

PROTECTIVE COATINGS

Plating Room Layout. G. R. Kentta. (*Met. Fin.*, 1958, **56**, Sept., 52–56). Factors in choice of equipment as well as its disposition are suggested including future expansion requirements.

Hard Chromium Plating on Locomotives. W. Schmitt. (*Metalloberfläche*, 1957, **11**, Nov., 370–372; Dec., 401–402). Using the hard Cr plating of locomotive bearings as an example, the importance of a thorough preparation and suitable quality of the surface was illustrated. It was shown that surface roughness increased with the thickness of the Cr deposit.—L. D. H.

An Investigation of the Anodic Passivation of Iron. B. Lovreček and K. Bošnjak-Moslavac. (*Zastita Mat.*, 1957, **5**, Jan., 9–11). Ni was used as anode in Cr plating processes and potential-current curves and weight loss were determined.

Corrosion-proofed Steel Screws. G. Becker. (*Draht, German Ed.*, 1958, **9**, Jan., 13–15). A chrome diffusion surface protection process is described, and the properties and uses of the products are given.

The Behaviour of Some Structural Materials in Electroplating. H. Hefele. (*Metalloberfläche*, 1958, **12**, Feb., 49–53). The author, after illustrating some examples from practice and model investigations, describes two defects occurring with case-hardening steels and their effects on direct Cr plating and electrolytic polishing. These defects, hairline cracks, and the breakdown of the hardened steel by tempering action—are basically due to incorrect heat treatment during hardening and particularly during grinding.—L. D. H.

Stripped Parts are Ready for Replating. (*Steel*, 1958, **142**, Feb. 3, 112–113). The method and advantages of using "Metex M-629" for stripping Cr plate from Ni plated car bumpers are described. Some acerue from the solution being made from a solid salt; other points are—gas fuming is no problem: the nickel is ready for re-plating.—D. L. C. F.

The Present Position of Nickel Plating Processes. Budkovic. (*Zastita Mat.*, 1957, **5**, Aug., 285–291).

Bright Nickel Plating. D. J. Fishlock. (*Prod. Fin.*, 1958, **11**, Jan., 48–62; Feb., 80–94; Mar., 87–101). The basic solutions are discussed with notes on the uses and extent of application of bright plating. Brighteners are tabulated. (35 references). Pre-treatment is then reviewed, especially the barrel processes and preparatory treatments of degreasing or acid etching type. Plant is surveyed and illustrated with notes on power supplies, agitation and anodes. (27 references). Methods of vat control, Hull plating cell tests and examination of thickness, ductility, internal stress, and porosity are described. The purification of solutions by electrolytic, chemical and carbon adsorption processes is discussed.—A. D. H.

Investigation of the Behaviour of the pH Value in a Non-Electrolytic Nickel Bath. L. Bosdorf and K. Müller. (*Metalloberfläche*, 1958, **12**, May, 150–151). The influence of sodium glycolate and lactate on the maintenance of a constant pH value in a nickel plating bath using hypophosphite was investigated. With a concentration of 30 g/l of glycolate, a thickness of coating of 34·5 μ was obtained.

Oil Pores in Galvanic Nickel Deposits. K. Sommer. (*Metalloberfläche*, 1957, **11**, Nov., 366–367). A description is given of a species of pinhole formation caused by liquid oil or grease. It is suggested that such pores be called "oil pores" to correspond to the English term "grease etching."—L. J. L.

Galvanising Cast Iron. A. Hiscock. (*Fond. Belge*, 1958, **28**, Mar., 79–87; *Zinc. Cadmium et Alliages*, 1957, Apr.-June). This article gives the results of a detailed investigation of problems connected with the galvanizing of iron castings. The report deals with practical difficulties encountered, the effects of time of immersion, temperature, and iron composition on the properties of the coating, in the case of grey, white and malleable castings. The article finally deals with economic considerations.—L. D. H.

The Girder Galvanising Works of the Metallurgical Society of Aisne. (*Mét. Constr. Mécan.*, 1957, **89**, Dec., 1033–1040). This article describes the lay-out of the works, storage and mechanical preparation of girders, chemical preparation, heating plant and the galvanizing process for steel pipes. A semi-continuous process is operated.—R. P.

Thickness of Coating, Shape and Calculation in Jobbing Galvanising. W. Derenbach. (*Metalloberfläche*, 1958, **12**, Mar., 84–87). In calculating costs for this type of work the shape of the object to be galvanized must be taken into account in assessing the thickness of coating and the galvanizing time.—L. D. H.

The Effect of Hot Galvanizing on the Mechanical Properties of Malleable Cast Iron. Z. Hostinský. (*Slévárenství*, 1958, **6**, (2), 31–34). [In Czech]. The reduction in impact strength of malleable-cast irons observed after hot galvanizing was investigated. It was found that this could be prevented by air or water quenching of the castings from 750° C prior to hot galvanizing. On tempering in protective atmospheres it is advantageous to cool the castings rapidly from 700–720° C immediately after termination of the stage of second graphitization.—F. F.

Plating of Castings. Developments in the Light of Present-Day Knowledge. (*Found. Trade J.*, 1958, **104**, Feb. 20, 211–212). A new process developed in France for the zinc plating of cast iron is briefly described.

Aluminising Gas Turbine Blades of Austenitic Steels. V. I. Prosvirin, A. I. Fedosov and Yu. S. Myakishev. (*Metall. Obra. Met.*, 1956, (4), 50–56). Experimental results show that by using thermal diffusion saturation of Al and Cr, it is possible to increase a few times the resistance to erosion of gas turbine blades without any resulting change in their strength.

Conductor Wire Plated Continuously. (Steel, 1958, **142**, Mar., 24, 118, 121). Copper coating of a steel core by Western Electric Co., Baltimore is described. A continuous line carries out 32 processes on 50 strands simultaneously.

Gold Coating Costs Reduced by New Process. (*Ind. Fin.*, 1958, **9**, Dec., 993.) A chemical dip process, "Atomex" is briefly described.

Recent Developments in Metal Spraying. H. Reininger. (*Metalloberfläche*, 1957, **11**, Nov., 361–365). A review of protective coatings against corrosion and scaling, of the lining of bearings, and the metallization of flat surfaces. (31 references).—L. J. L.

The Technical Problem of Metallisation. M. Pajevic and L. Junker. (*Zastita Mat.*, 1957, **5**, June, 204–209). A review of metal spraying for industry is given. Apparatus is critically surveyed.

Flame Spraying of Metals. D. E. J. Cunningham. (*Corros. Techn.*, 1958, **5**, Mar., 71–74). The author briefly describes the different types of powder and wire guns produced by the Schori division of F. W. Berk & Co., and indicates the most suitable coatings for different environments. Typical examples of successful applications are given.—L. E. W.

Low Cost Hard-facing by Spraying. J. R. Franklin. (*Corros. Techn.*, 1958, **5**, Mar., 75–76). The author describes how the 'Thermo Spray' gun and associated 'Thermo Spray' fluxes and coating powders can be used to apply hard, wear-resistant coatings at high speed and with high efficiency.—L. E. W.

Protection of Steel Constructions Against Corrosion by Metallisation. 2. Protic. (*Zastita Mat.*, 1956, 1956, **4**, June, 202–203). An account of sprayed coatings, mainly from British sources.

Mechanized Surfacing with Alloy Materials. R. S. Zuchowski and J. H. Neely. (*Weld. J.*, 1958, **37**, Jan, 22–29). A review, particularly of inert-gas W-electrode hard surfacing with addition of WC; inert-gas consumable-electrode surfacing with cold-wire addition and submerged-arc surfacing with or without powder alloy additions. The operations and welding apparatus are illustrated.

New Processes for the Protection of White Iron. S. Dikic. (*Zastita Mat.*, 1956, **4**, July, 239–240). Passivation processes are reviewed for use under various corrosive conditions.

Ebonizing Stainless Steels. (*Ind. Fin.*, 1957, **9**, Dec., 1000). Cr–Ni and Cr stainless steels are treated by immersion in a molten bath of dichromates at 730–750° F for 15–30 min which forms a smooth black oxide film.

Metal Coloration. II. Colouring of Iron and Steel. R. Hoeltgen. (*Metallwarenind. und Galvanotechnik*, 1957, **48**, May, 214–215). Mixtures and methods for colouring iron brownish-black, black and blue are given.

CLAD SHEET AND HARD-FACING

Zirconia and Alumina Coatings Give Short-Time 3000° F Steel Protection. J. V. Long. (*S.A.E.J.*, 1958, **66**, Aug., 74–75). Flame spraying of refractory oxides with Al is described.

"Rokide". A New Method of Coating by Spray Gun. E. Sanchiz Bueno. (*Met. Elect.*, 1958, **22**, Aug., 79–82). [In Spanish]. The value of high temperature protection is discussed and the characteristics of the three fused refractory coatings (alumina, zirconia and zirconium silicate) that are made by the Rokide process are described. Their properties are also given in tabular form.—P. S.

Properties and Applications of Flame-Sprayed Refractory Coatings. L. Manuel. (*Met. Fin. J.*, 1958, **4**, Aug., 313–316). Alumina and zirconia coatings are described and their general properties indicated.

Babbitting of Cast Iron. (*Found. Trade J.*, 1958, **105**, Sept. 4, 295–296). "Kolene" process pre-treatment of cast iron for coating with bearing metals is described. The surface is first reduced and then oxidized in a salt bath by electrolytic means. Plain, ungrooved iron surfaces are preferred. Bearings up to 6-t in weight can be handled.

Bonderizing Process Used for Pre-Painted Steel Strip. (*Ind. Fin.*, 1958, **10**, Sept., 40–41).

POWDER METALLURGY

Getting More from Metal Powders. (*Met. Prog.*, 1958, July, 101–104). New developments in powder metallurgy are discussed, they include: holders for carbide tools, use of metal (copper) powders for barrel finishing, and employment of the slip casting process for large, complicated parts.—T. G.

Slip Casting of Metal Powders. H. H. Hausner. (*Powder Met. Bull.*, 1958, **8**, June, 53–67). The process is described and data on the properties of loose and compacted powders, particle size and apparent density, compositions and viscosities of slips and effects of water content and of shrinkage on sintering are given for stainless steel.

Simple Gas-Tight Furnace for Induction Heating. R. D. Grinthal. (*Powder Met. Bull.*, 1958, **8** June, 68–69). A quartz tube furnace with brazed joints is described.

Pick Right Atmosphere to Sinter Iron. (*Steel*, 1958, **143**, July 28, 80–81). The effects of 5 atmospheres on compacts containing over 80% Fe have been studied. Recommendations are made, which enable stronger iron-carbon compacts to be made.—A. G.

FERRITES, CERMETS, AND CARBIDES

Grain Growth in Nickel Ferrites. P. Levesque, L. Gerlach and J. E. Zneimer. (*J. Amer. Ceram. Soc.*, 1958, **41**, Aug., 300–303).

Magnetic Spectra of Manganese Ferrites. S. E. Harrison, C. J. Kriessman and S. R. Pollack. (*Phys. Rev.*, 1958, **110**, May 15, 844–849).

Cation Distribution and Magnetic Moment of Manganese Ferrite. F. W. Harrison, W. P. Osmond and R. W. Teale. (*Phys. Rev.*, 1957, **106**, June 1, 865–866). **Magnetic Anistropy of Cobalt Ferrite.** ($Co_{1\cdot01}Fe_{2\cdot00}O_{3\cdot48}$) **and Nickel Cobalt Ferrite** ($Ni_{0\cdot72}Fe_{0\cdot39}Co_{0\cdot89}Fe_2O_4$). H. Shenker. (*Phys. Rev.*, 1957, **107**, Sept. 1, 1246–1249).

Origin of Magnetic Anisotropy in Cobalt-Substituted Magnetite. J. C. Slonczewski. (*Phys. Rev.*, 1958, **110**, June 15, 1341–1348).

The Conformity to the Additive Principle of Intensity of Magnetisation in Complex Alloy Ferrites. S. N. Krasotskaya. (*Fiz. Met.*, 1957, **5**, (2), 241–245).

Domain Structure Effects in an Anomalous Ferrimagnetic Resonance of Ferrites. R. C. Le Craw and E. G. Spencer. (*J. Appl. Phys.*, 1957, **28**, Apr., 399–405).

Alumina Base Cermet (II). Effects of Additives on the Adhesion between Alumina and Iron. H. Matsumoto, S. Yamauchi and G. Nishiyama. (*Rep. Gov. Ind. Res. Inst. Nagoya*, 1958, **7**, July, 543–552). [In Japanese]. The sintering temperature of Al_2O_3 is 1700–1800° C and that of iron 1200–1300° C Additions were made to reduce the former and contact angle and bending and compressive strength were measured. Additives generally reduce contact angle, but diffusion reduced mechanical strength of the iron.

Slip Casting. L. M. Schifferli, jun. (*J. Metals*, 1958, **10**, Aug., 517–521). A description is given of the technique of slip casting, and its application to the casting of high-temperature materials including ceramics and metallo-ceramics.

Ceramics for Machine Tools. R. M. Gill and G. Spence. (*Ceramics*, 1958, **9**, Aug., 30, 32–34; Sept., 27–31). A review of compositions, structures, and physical properties is given with data on performance. (15 refs. and bibliography).

A Contribution to the Problem of Crystal Growth During the Production of Sintered Carbides. B. Čech. (*Neue Hütte*, 1958, **3**, May, 300–302). The relationships between structure and strength of carbide alloys are exemplified by the Cr_3C_2–Ni alloys. The effects of the grain size of the carbide constituent, and of the crystal size of the metallic binder on the strength of the Cr_3C_2–Ni alloys are discussed.—L. J. L.

PROPERTIES AND TESTS

New Properties and Applications of High Purity Metals. G. Chaudron. (*Rev. Mét.*, 1958, **55**, May, 407–416). New techniques make possible the purification of many common metals down to a few parts per million of foreign elements. The physical properties of such high-purity metals are discussed, including high conductivity, corrosion-resistance and the phenomenon of polygonization.

Temperature Dependence of the Vibration Decrement and Modulus of Elasticity of Certain Steels. M. M. Pisarevskii. (*Vestnik Machin.*, 1954, (8), 61–65). Various samples of steel shaped like tuning forks, and subjected to strain and temperature, photoelectrically recorded their oscillation in a film oscillograph. The temperature/stress curves thus obtained showed the functional dependence of the vibration decrement on the composition, stress and temperature factors. The results of repeated heat treatments of steels are also given.—S. I. T.

Determination of Equicohesive Temperatures. R. Tambhankar. (*Tisco*, 1958, **5**, Jan., 10–24). The author first describes methods for determining equicohesive temperature and for ascertaining its dependence on grain size, strain and strain rate. The application of these methods to an austenitic Ni–Cr (35/10) alloy-steel and to Armco iron is described and the results are presented and discussed. A number of photomicrographs is included. (17 references).—L. E. W.

A Study of the Relationship Between the Bonding Forces and the State of the Crystals in Metals and Solid Solutions. V. A. Il'ina, V. K. Kritskaya, G. V. Kurdyumov, Yu. A. Osip'an and T. I. Stelletskaya. (*Fiz. Met. i Metalloved.*, 1957, **4**, (3), 417–431). The effect of heat treatment and deformation on the interatomic bonding forces of Cr, Ta, W and of the solid solutions Fe–Cr, Fe–W, Fe–Mn and Fe–Ti are studied by measuring the characteristic temperature and the modulus of elasticity.

Elastic Interaction of Interstitial Atoms in Body-Centred Cubic Crystals. J. C. Fisher. (*Acta Met.*, 1958, **6**, Jan., 13–18). The elastic distortion near interstitial atoms is estimated by an atomistic relaxation process. The binding energy of an interstitial pair is calculated and found to agree with an experimental value of 2 kg.cal/mol.—A. D. H.

Continuous Distribution of Dislocations. IV. Single Glide and Plane Strain. B. A. Bilby, R. Bullough, L. R. T. Gardner and E. Smith. (*Proc. Roy. Soc.*, 1958, **244**, Apr. 22, 538–557).

Relaxation of Special Steels. Tummers and W. Soete. (*Rev. Soudure*, 1957, **13**, (4), 239–245). This report to Commission X of the International Institute of Welding describes tensile and torsion tests that have been used to study stress relaxation. Data obtained in different laboratories at temperatures up to 800° C on various Mo, Cr–Mo, Cr and Ni–Cr steels are presented in tabular and graphical form.—B. C. W.

Tensile Strength and Bending Angle of Fusion-Welded Notched Specimens. H. Fiehn and K. Teske. (*Schweissen Schneiden*, 1958, **10**, Mar., 90–93). After verifying on samples of unwelded sheet that notched tensile and bending tests could provide numerical values of strength and bending angle, large scale notch tests were carried out on welded samples of St 37, St 42, St 52. boiler plate II, 19 Mn 5 and 13 CrMo 44. The values obtained were confirmed by industrial trials.—L. D. H.

The Effect of Preloading on the Yield-Point in Iron. M. M. Hutchison and N. Lonat. (*Acta Met.*, 1958, **6**, Jan. 8–12). The yield-point of Armco iron was measured after preloading at 65–150° C below the yield point to distinguish between current yield point theories. A model is advanced in which, prior to yielding, the dislocations move significantly, carrying their atmospheres with them.—A. D. H.

Characteristic Behaviour of Heat-Resisting Alloys Under Constant Stress. F. Vitovec. (*Berg-Hütten Monatsh.*, 1957, **102**, Dec., 297–303). The results of testing the behaviour of some heat-resisting alloys are discussed, including tensile properties, notch sensitivity, velocity of deformation, compression and bending tests. Notched and unnotched specimens were used. (18 references.)—R. P.

The Significance of the Relative Dimensions of the Cross-Section Area of Flat Specimens of Low-carbon Alloy Steels, in the Computation of Their Plastic Properties. I. P. Obozov and V. V. Shevelev. (*Zavods. Lab.*, 1958, **24**, (1), 84–85). In specimens of malleable materials the value of the relative elongation and relative constriction under equal conditions, depends on the shape and relative dimensions of the cross-section. This fact renders necessary the investigation of the relation between the width and thickness of the specimen. Formulæ are given for the calculation of the relative construction and elongation and for computing the margin of error inherent in these determinations.—L. H.

Some Tests on a Conical Test Ingot. (*Fonderie*, 1957, Aug., 363–366). Test bars used in several French steel foundries are compared and results presented statistically. The resistance to tensile fracture is known with the greatest and elongation with the least accuracy.—R. P.

Machine for Bend Tests. (*Steel*, 1958, **142**, Feb. 3, 114). A machine designed by Philips Research Laboratories, (Holland), to give a reliable bend test, is described. With a single hand operation a specimen can be bent smoothly over a correct radius through any angle between 0 and 180°. The same principles can be applied to a larger machine for testing heavier plates, wires or bars.—D. L. C. P.

Construction, Operation, and Application of a Novel Universal Bending Test Apparatus. W. Köhler. (*Werks. Korr.*, 1958, **9**, Apr. 216–227). A detailed description of the apparatus and its calibration is given; results are reported of tests on ferrous and non-ferrous metals, plastics, and wood to demonstrate the universal applicability of the apparatus.

A Recording Torsion Testing Machine for Wire. H. C. Burnett. (*Amer. Soc. Test. Mat., Bulletin*, 1958, Jan., 68–69). An entirely frictionless (spark) recording system is used.

Impact Resistance of Carbon Steel Castings. Z. Nagy. (*Koh. Lapok*, 1957, **12**, July, Öntöde, 149–157). The author discusses the effect of the chemical composition, crystallization, inclusions, diffusion annealing, normalizing, normalizing and tempering, hardening and tempering and welding on the impact resistance of carbon steel castings. He states that for achieving high impact values Mn more than 0·7%, Si + 4 Al more than 0·35–0·6%, P and S less than 0·03% are desirable.—P. K.

Method of Preparing Impact Specimens of Austenitic Steels and Welded Joints for Investigating the Transformation $\gamma \rightarrow \sigma$. B. I. Medovar and Yu. B. Malevskii. (*Zavods. Lab.*, 1958, **24**, (2), 208–210). Local cold working accelerates the process of sigma phase formation, and a concentration of the phase near the notch of a Mesnager specimen reduces the observed impact strength by as much as 20%. The precautions necessary when preparing the notch impact specimen to prevent this occurring are outlined.—L. D. H.

The Effect of Temperature on Notch Impact Toughness and the Appearance of the Fracture Face of Steel in the Transition Range from Mixed Fracture to Brittle Fracture. A. Schepers and F. R. Licht. (*Stahl u. Eisen*, 1958, **78**, Feb. 20, 227–235). A linear relationship between notch-impact toughness and the relative bending angle exists for all steels studied in the transition range from mixed fracture to brittle fracture. The steels included killed O.H. steels and a rimming basic Bessemer steel. The decrease of the relative bending angle with decreasing temperature begins when the crystalline proportion of the fractured area has reached about 70% of the total area. The crystalline proportion of the fractured area is a better criterion for brittle fracture than the notch impact toughness.—T. G.

Improved Notch-Toughness of Experimental Semi-Killed Steels Over One Inch in Thickness. R. W. Vanderbeck. (*Weld. J.*, 1958, **37**, Jan., 10s–20s). A substitute for ABS Class C killed ship-plate steel was sought and heats from two 25-t basic O.H. furnaces were tested with lower C and higher Mn. This proved to be tougher and could be an emergency substitute for, if not an alternative to ABS Class C steel of 1–1¼ in. thickness. A standard is suggested.

On the Character of the Deformation of Cast Iron of High Strength. K. V. Kovalev and A. A. Novik. (*Vestnik Machin.*, 1954, (5), 69–72). [In Russian]. Results are given for tensional and torsional deformation of Mg spheroidal graphite, Cr–Ni–Mo and plain cast iron. The modulus of longitudinal deformation of cast iron with spheroidal graphite is much higher than that of cast iron with flake graphite. In general, with the increase of the limits of strength, there is an increase of moduli of deformation.—S. I. T.

Influence of Plastic Deformation on the Barkhausen Effect. K. Votruba. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (9). 1246–1249). The materials dealt with by the author in his systematic study of the influence of plastic deformation on the Barkhausen effect included iron. For iron the effect was found to

fall slowly with increasing deformation and to rise for NiFe.—S. K.

A Study of the Non-Uniformity of Plastic Deformation During Torsion By Using a Milled "Grid." T. K. Zilova, N. I. Demina and Ya. B. Fridman. (*Fiz. Met. Metalloved.*, 1957, **4**, (3), 455–469). A "grid" was milled on the specimen of 40KhNMA steel hardened and tempered at various temperatures and the distribution of deformation at the surface was studied during torsion. Mechanical or electrolytic polishing were suggested as final treatment for reducing the unevenness of deformation.—R. S.

Work Hardening and Residual Stress in Boring of Constructional Steels. P. E. D'yachenko and N. A. Podosenova. (*Vestnik Machin.*, 1954, (7), 45–47). [In Russian]. Work hardened and subsequently annealed steel rings were subjected to boring at speeds, varying from 5 to 500 m/min. The effects of speed, longitudinal feed and other factors were studied. The optimal speed of boring, varied with the nature of the steel objects from 200 to 500 m/min, the optimal radius of sphericity of cutting edge $\rho = 15$ mk.—S. I. T.

The Influence of the Preliminary Working of Austenite Steel on Its Durability. J. A. Oding and A. P. Shichkova. (*Vestnik Machin.*, 1954, (7), 40–44). The experiments consisted in the quenching and ageing of samples of steel at temperatures varying from 450° to 750° C and a time of ageing of from 25 to 400 h. Some samples were quenched and work-hardened. The influence of this treatment on the structure and durability of steel was studied and it was found that the preliminary thermal treatment may in certain conditions diminish the durability of steel.—S. I. T.

Influence of Cold Working on the Damping of Iron–Chromium Alloys. K. Bungardt and H. Preisendanz. (*Arch. Eisenhüt.*, 1958, **29**, Apr., 241–247). Damping measurements made on pure iron, pure Cr and Fe–Cr alloys with 6–45% Cr, in the quenched and cold-rolled conditions showed that the maximum damping values at about 220° and 600° C occurring, after quenching from high temperatures, in Fe–Cr alloys with high Cr and low N contents are strongly influenced by cold working. The 220° maximum is depressed with increasing cold working, and a new maximum appears between 300 and 350°. The 600° maximum disappears after cold working. The results are discussed.

Investigation of the Localisation of Plastic Deformation under Complex Stress Conditions During Creep. I. A. Oding and G. A. Tulyakov. (*Zavods. Lab.*, 1957, (12), 1478–1480). The measurements were based on the following procedure: On the surface of a tubular testpiece of 25 mm external diameter, along a generatrix, imprints were made with a diamond pyramid tester on a Vickers machine every 10 mm along the whole gauge length of the specimen of 100 mm. The testpiece was then submitted to complex stresses and measurements were taken of the elongation and the transverse displacements. Thus the relation between elongation and displacement were established. These results are tabulated for various conditions of stress, temperature and types of steel.—L. H.

Change of Length during Transformation of Iron under Stress. M. de Jong and G. W. Rathenau. (*Nature*, 1958, **181**, May 17, 1396–1397). Fine grained iron (containing N_2) was strained through a α–γ–α cycle *in vacuo* and volume change, over a wide range of heating rates, plotted as a straight line. Coarse grained specimens showed greater scatter. The phenomena are discussed but no complete explanation can be given. The process is not one of creep.

Investigation of the Distribution of Properties in the Surface Layer During Mechanical Treatment of Steel. I. L. Mirkin and T. A. Sirenko. (*Metallov. Obra. Met.*, 1955, (2), 50–56). The strain-hardening of steel 50 with sorbitic structure, occurring during uniform plastic deformation (uniaxial tensile load) is characterized by an appreciable increase in microhardness, which in the section adjoining the neck of the test pieces increases by over 70–80 units. The relation between the microhardness and the true normal pressure is $S = H_v(0{\cdot}32 \pm 0{\cdot}01\%)$ with an average range of $\pm$ 3%.—L. H.

Dynamic Calibration of Fatigue Machines. J. Kalbfleisch. (*Rev. Met.*, 1958, **55**, Feb., 166–178). The calibration of fatigue machines under dynamic conditions requires apparatus of low inertia, particularly when high frequencies are involved. It is shown that resistance wire gauges are very suitable for the calibration. The improvements made in the dynamic calibration of fatigue machines has enabled the machines to be improved so as to comply with the tolerances recommended by the International Institute of Welding.—B. G. B.

Fatigue Failures in Fatigue Machines. W. H. Munse. (*Weld. J.*, 1958, **37**, Feb., 54s–56s). It is shown that welded flexural members which are subjected to many millions of cycles of loading may fail at relatively low maximum nominal stresses.—U. E.

Fatigue Fracture. W. H. Munse. (*Rev. Soudure*, 1958, **14**, (1) 59–66). A discussion of fatigue fractures occurring in large fatigue testing machines and in the hull of a ship.

Fatigue Fractures and How to Avoid Them. (*Aciers Fins Spec.*, 1957, Dec., 48–57). The nature of fatigue is discussed. Failure may be due to imperfections on the macro- or micro-scale. Conditions of transformation, dimensions, shape and surface state govern fatigue fracture. In steels, the path of fatigue cracks is intercrystalline and preferentially affects the ferrite crystals.—R. F.

Form of the Test Piece for Fatigue Testing of Hardened Steel. I. E. Kolosov. (*Zavods. Lab.*, 1958, **24**, (1), 90–91). After discussing the results of a number of determinations of the fatigue strength several hardened steel specimens, recommendations are made for the dimensions of a suitable test piece.—L. D. H.

Surface Fatigue of Carbo-Nitrided Steel. G. W. Powell, M. B. Bever and C. F. Floe. (*Met. Prog.*, 1958, **73**, Mar., 67–69). Pitting of worn surfaces is shown to be related to case depth and retained austenite. With carburized surfaces, case depth is the prime factor. A simple testing machine for testing in pure roll was constructed. The test ran at the rate of $\sim 10^5$ cycles per week and cycles to failure and compressive stress were observed.

Investigations of Impact Fatigue. N. N. Davidenkov and E. I. Belyaeva. (*Metall. Obra. Met.*, 1956, (11), 4–10). Six different types of alloy steel with different thermal treatments, were subjected to parallel tests for determining the limiting fatigue (at 10^8 cycles) in static and dynamic stresses. Results showed that the relation of the impact to the static fatigue for over-heated steels was 1·14–1·19, for normalized steels with tempering at high temperature 0·97–1·01 and with medium tempering 0·90—0·91, whilst the relation of steels tempered at low temperature was 0·80–0·86–0·91. Some explanations are suggested for this phenomena, which however, the author considers, ought to be further studied.—L. H.

A Statistical Presentation of the Results of Fatigue Tests. J. Strebelle. (*Rev. Soudure*, 1958, **14**, (1), 24–32). A theoretical statistical study of the significance of the results of fatigue tests.

Fatigue Tests Proved by 3 Statistical Checks. L. G. Johnson. (*S.A.E.J.*, 1958, **66**, Mar., 71–73). Formulæ and probability curves are given for estimating when failure will occur, how accurate this answer is, and whether this product is an improvement on those previously tested.

The Mechanism of Fatigue: A Review. R. C. A. Thurston. (*Can. Min. Met. Bull.*, 1957, **50**, Dec., 708–716). Previous theories are briefly stated and metallographic observations are surveyed and illustrated as are X-ray diffraction and observations of crack growth. (43 references).

Fracture of Metals: Some Present-day Thoughts on Crack Initiation and Propagation. W. D. Biggs. (*Iron Steel*, 1958, **31**, Feb., 57–60). The author reviews current ideas on the initiation and propagation of fracture in metals, with particular reference to the microcrack theory of Griffiths. (42 references).

Contribution to the Study of the Possibilities of the Utilisation of Quality Steels in Working Conditions involving Fatigue. M. M. Alvaro Periane and J. M. Pintado Fe. (*Tecn. Met.*, 1957, **13**, Sept.-Oct., 195–231). [In Spanish]. A study of the fatigue behaviour of two steels (0·33%C, 0·60%Cr, 2·40%Ni and 0·31%C, 0·5%Cr, 2·2%Ni and 0·27%Mo) has been made with particular reference to notch sensitivity and the determination of basic data for the design of components in these steels. A review of the literature was made and it was concluded that it is necessary to know the shape of the curves $\sigma_e = f(\sigma_r)$ for values of K_t between 1·25 and 4, (σ_e is the fatigue limit, σ_r the rupture stress, and K_t the stress concentration factor). Consequently, *S–N* curves for each steel were determined for σ_r of 100, 120, 140 and 160 kg mm^{-2}, with K_t of 1, 1·266, 1·46 and 1·86, and summarized results of the 234 tests are given. The practical applications of this study are then discussed and an appendix deals with methods of calculation and the factors that influence fatigue strength. (78 references).—P. S.

A Theory of the Origin of Fatigue Cracks N. F. Mott. (*Acta Met.*, 1958, **6**, March, 195–197). On the basis that dislocations in a slip band can move backwards and forwards, a model is given to explain how a crack can develop.—A. D. H.

The Effect of Different Surface Treatments on the Fatigue Strength of Drill Steel. T. W. Wlodek. (*Can. Min. Met. Bull.*, 1958, **51**, Feb., 89–98, discussion 98–101). Shot peening, induction hardening, spiral rolling and combinations of these are examined. Plain carbon SAE 1080 and Ni–Cr–Mo steels have been used and *S–N* curves obtained. Spiral rolling appeared to the most effective treatment. (26 references).

On the Theory of the Destruction of Metals by Cyclic Loads. I. A. Oding. (*Metallov. Obra. Met.*, 1955, (2), 4–8). The increase in the vacancies of the crystal lattices, especially on the surface, promotes the formation of micro-pores and micro-cracks. In the first stage of the symmetric cycle, the dislocation is caused by the stress loads which cause changes in the crystal lattice. These changes hinder the destruction of the dislocated parts in the second part of the cycle, i.e. during the unstressing of the test specimen. The third quarter of the cyclical process is the new stress, which is characterized by the formation of other vacancies, but of opposite sign to the first, and the fourth quarter which follows is not basically different from the second. The theory of vacancies in the crystal lattice explains the dual character of the fatigue failure mechanism in metals.—L. H.

Identification of the Sources of Fatigue Cracks in Anisotropic Metal. H. de Leiris and V. Corfa. (*Rév. Met.*, 1958, **55**, Feb., 101–106). The identification of the beginning of a fatigue crack is usually made by examination of the surface. However if the metal is insufficiently isotropic the method is inadequate. In such cases it is possible at the stage where the break is no more than a fissure to use a careful examination of the external path of the fissure to identify the source of the fatigue crack. The identification is greatly facilitated by the use of the Jacquet-Van Effenterre replica technique.—B. G. B.

Method of Investigating the Thermal Endurance of Steel and Alloy Sheet. M. V. Pridantsev and A. R. Krylova. (*Zavods. Lab.*, 1958, **24**, (2), 204–205). A method is described for studying thermal fatigue in sheet metal. A square specimen is used, with five central holes, the sheet being fixed rigidly at the corners, and exposed to an alternating heating and cooling cycle. Up to six specimens can be examined simultaneously. The results are discussed.—L. D. H.

The Influence of Surface Work-Hardening by Means of Shot on the Limited Durability of Samples on Repeated Impact. M. A. Anuchin and Yu. A. Volkov. (*Vestnik Machin.*, 1954, (8), 55–58). Experiments on cast iron shot hardening of Cr–Ni–Mo and carbon steel has shown that a long 40 min heating of samples before repeated impact only markedly increases their limited longevity when the

temperature of heating does not exceed 150° C. Other factors are also discussed.—S. I. T.

Fatigue Strength of Steel, Surface Hardened at a High Frequency Heating on a Machine and Valve Generator. P. A. Lankin. (*Vestnik Machin.*, 1954, (8), 53–55). The experiments carried out on the surface hardening of billets of steel in an inductor at high-frequency showed satisfactory results.—S. I. T.

Fatigue in Mining and Construction Equipment. B. M. Hamilton. (*Can. Min. Met. Bull.*, 1957, **50**, Dec., 717–724). Failures in service are illustrated and discussed after a brief account of operating stress, endurance limit and the influence of surface conditions, including corrosion and fretting.

A High-Temperature Centrifuge for Creep, Rupture and Bend Tests. I. I. Kornilov. (*J. Met.*, 1958, **10**, Mar., 187–189). The apparatus work up to 1200° and up to 100 kg/mm².

An Interpretation of the General Equation for the Creep of Metals. I. A. Oding. (*Doklady A. N.*, 1957, **116**, (1), 66–69). Mathematical deductions show that the curve of metal creep should be considered as the resultant of two curves: the curve of damped creep, determined by processes occurring on the grain boundaries, and the curve of increasing velocity of creep determined by processes occurring inside the grains.—S. I. T.

Creep Tests in High-Pressure Atmosphers. (*Met. Treatment*, 1958, **25**, Jan., 31–32). Work by the G.E.C. on a stainless steel vessel is reported.

Creep in Austenitic Steels under Conditions of Complex Stressing. I. A. Oding and G. A. Tulyakov. (*Izvest. Akad. Nauk., Otdel. Tekh.*, 1958, (1), 3–10). Creep was investigated in an austenitic steel (type 1Kh18N9T) under complex tensile and torsional stresses, using a thin-walled tubular specimen.

Creep and Failure of Tubes under the Action of Internal Pressure. Sh. N. Kats. (*Izvest. Akad. Nauk, Otdel. Tekhn.*, 1957, (10), 86–88). In this work an attempt is made to determine the time to failure of an internally pressurized tube through an analysis of the creep of the tube at finite deformations.—S. K.

Creep with Variable Loads Under the Conditions of a Complex Stained State. V. S. Namestnikov. (*Izvest. Akad. Nauk Otdel. Tekhn.*, 1957, (10), 83–85). The results are presented of experiments in which thin-walled tubular test-pieces were used to study creep with torsional and tensile stresses. Type EI 257 steel was used and it was found that preliminary extension (torsion) had no effect on subsequent torsion (extension). With simultaneous torsion and tension, the hardening effect of the previous test becomes evident when the parameter λ does not change appreciably during the following test. With variable loads the proportionality of the deviations of stress and deformation breaks down.—S. K.

A Study of the Zone of Failure in Creep. I. L. Mirkin and I. I. Trunin. (*Metallov. Obra. Met.*, 1957, June, 2–7). It is established that microhardness near a crack produced by creep testing is lower than in the bulk of the metal, and it is explained as due to microporosity or accumulation of vacant sites in the lattice in these zones. The band affected is about 100 μ wide and the greatest lowering observed is ~ 12–14%. (11 references).

The Influence of Residual Stresses on the Buckling of Steel Columns. B. Thürlimann. (*Schweiz. Arch. Wiss. Techn.*, 1957, **23**, Sept., 388–404). The influence of residual stresses on the buckling load is discussed and experimental details for measuring residual stresses on rolled shapes, welded and riveted parts are given. Two methods of calculating column buckling curves are explained. The influence of residual stresses on other stability problems in steel construction is discussed. (16 references).—B. P.

A New Portable Hardness Tester. (*Ind. Fin.*, 1958, **9**, Dec., 1013). The machine weighs only 700 g, can be used for Focke-Wulf, Rockwell and Vickers tests, and is made by Karl Frank G.m.b.H., Weinheim-Birkenau.—A. D. H.

On Indentation Hardness Testing. I. S. Yazawa, M. Unno, I. Sawano and S. Yamamoto. (*J. Mech. Lab.*, 1958, **12**, Jan., 18–21). [In Japanese]. Metal-plated steel blocks were used with a thickness (of Zn, Cu or Sn) not more than 1μ. The difference between plated and unplated portions is shown to be due to differences in friction between indenter and surface. It is considered that the same surface conditions should be ensured in hardness testing.

Relationship between Scleroscope, Rockwell and Brinwell Hardness Readings. N. R. Arant and J. J. Marsalka. (*Iron Steel Eng.*, 1958, **35**, Feb., 160–161). Results from a comprehensive test programme are presented as graphs giving conversions between results from the Shore C-2 Scleroscope (used on stand), Rockwell C and Brinell testers. They apply to steel bar, chill iron and grain iron standards.

On Ball Indentation. I. Experiments on Specimens of Definite Dimensions. S. Yazawa, K. Sato, M. Unno, M. Tsutsumi and G. Yaguchi. (*J. Mech. Lab.*, 1958, **12**, Jan., 22–30). Steels with 0·19 and 0·24% C were used with 22 mm specimens and a $\frac{1}{8}$ in. ball. The differences between radii of curvature were not over 3 μ. A critical load was found above which profiles and Meyer indices and constants show charged behaviour. It is the load at which Lüder's lines reach to the edge of the specimens, it was 2500–3000 kg for both steels. Cu plating gave quite different Meyer indices and constants which appear to depend on frictional effects.

On the Brinell Hardness of Cast Irons. J. Van Elghem. (*Fond. Belge*, 1958, **28**, Feb., 58–60). The problem of selecting the load (P) and the ball diameter (D) for Brinell hardness measurements on cast irons with a hardness of < 160 is discussed. From theoretical and practical considerations a P/D^2 ratio of 10 is preferred to one of 30, and a ball diameter of 10 mm is recommended.—B. C. W.

Hardenability Bands for Steels 6120-H to 8630-H. (*Met. Prog.*, 1958, **73**, Mar., 96B).

Influence of Steelmaking Practice on the Hardenability of Carbon Steels. L. Lambert. (*Centre Doc. Sidér. Circ.*, 1957, **4**, (11), 2241–2251). The influence of factors other than the chemical composition of the steel on the hardenability are considered. These include the FeO and MnO content of the slag, the ratio

$$\text{Kmn} = \frac{(\text{MnO})}{(\text{FeO})[\text{Mn}]}$$

and the rate of decarburation. Results obtained on a 50-t O.H. furnace and a 20-t electric furnace are described.—B. G. B.

Studies on Silico-Manganese Spring Steels. Part I: Influence of Carbon Content on Hardenability. S. N. Asthana, D. K. Sood and T. V. Cherian. (*Tisco*, 1958, **5**, Jan., 25–30). The authors present and discuss the results of an investigation to determine the effect of carbon content on the hardenability Si–Mn steels containing 1·8–2·0% and 2·0–2·2% Si. Experiments are also discussed in which the minimum carbon content required to obtain 50% martensitic structure in the centre of a $\frac{1}{2}$ in. plate was determined. It is concluded that the carbon content of 0·48–0·54% for the oil-quenching grade and of 0·33–0·38% for the water-hardening grade (as laid down in I.R.S. Specification No. M.11) do not satisfy the requirements for through hardening of a $\frac{1}{2}$ in. plate. The authors show that to achieve through hardening the carbon must be not less than 0·55% for oil-quenching and not less than 0·35% for water-hardening. **Part II: Influence of Quenching Temperature on Hardenability.** D. K. Sood and T. V. Cherian. (31–34). The authors present and discuss the results of experiments from which it is concluded that a quenching temperature of 875° C is sufficient for 0·55%C and above, and that for lower carbon contents a minimum temperature of 925° C is necessary. **Part III: Influence of Alloy Additions—Chromium and Silicon—on Hardenability.** D. K. Sood and T. V. Cherian (35–37). The authors found experimentally that an addition of about 0·25% Cr to the base composition of I.R.S. Specification No. M.11 Grade II enhanced the hardenability sufficiently to enable the camber test on $\frac{1}{2}$ in. plates to be passed. An analysis of the effect of silicon indicated that the hardenability factor for the element above 2·0% is higher when carbon is more than 0·55%.—L. E. W.

Oxygen and the Ageing of Pure Iron. W. Ganiche and H. Beck. (*Tech. Mitt.*, 1957, Dec., 295–305). This paper reviews present knowledge of the influence of oxygen on ageing, followed by a description and discussion of tests carried out with pure iron. It is concluded that oxygen causes age-hardening of pure iron. (18 references).—R. F.

Prolonged Ageing of Iron-Chromium-Cobalt Alloys. V. Z. Tseitlin and M. A. Filatova. (*Metall. Obra. Met.*, 1956, (1), 12–18). These alloys have comparatively great physical and chemical resistance properties between 650–700° for a very long period of time. The phase composition, structure, hardness and plasticity allow only relatively small changes during 10,000/12,000 h of testing between 650 and 700°. The main change observed in structure and phase composition occurred during the first 5000 h by maintaining the specimen isothermally at 650° —L. H.

The Effect of Grain Size on SNOEK-Damping and the Ageing of Carbon in Ferrite. H. J. Seemann and W. Dickenscheid. (*Acta Met.*, 1958, **6**, Jan., 62–63). Larger grain size was found to reduce ageing time and to have a still greater effect on the SNOEK-damping coefficient Q_m^{-1}. It is concluded that the proportionality factor relating the above to % C is fundamental for grain size over the range 0·9 to over 2·5. The effects of other alloying elements are, as yet, unknown; difficulties in quantitative evaluation of the C and N dissolved in steel have hitherto been encountered.

Discussion of Temper Brittleness, A Summary. V. D. Sadovskii. (*Metallov. Obra. Met.*, 1957, June, 24–31). A detailed discussion with 58 references of a number of papers appearing recently in this and other journals. Questions are raised and discussed: does temper embrittlement raise the ductile-to-brittle transition temperature Does tempering near AC, eliminate the tendency to temper-brittleness? Can transgranular failure occur in temper-brittle steel? Is impact strength impaired? Also the effects of Ni, P, C, Mo, W, Si, Al and N, the effect in plain carbon steels and of quenching, re-quenching, prolonged tempering and cold-work are also considered.

On the Origin of Reversible Temper Brittleness. L. Ya. Gol'dshtein. (*Metall. Obra. Met.*, 1956, (11), 36–39). The investigation showed two main states of the carbide phase in the Cr–Ni steel 33KhN3 to be distributed on the surface of the fracture, corresponding to the brittle and plastic states and depending on the rate of cooling after tempering at high temperature. The carbide phase occurring on the surface of the brittle fracture propagated along the grain boundaries (after slow cooling) is characteristic of the cementite lattice, whilst the carbide phase occurring on the surface of the plastic fracture, after rapid cooling, is characteristic of the distorted lattice of the cementite.—L. H.

The Mechanical Origin of Temper Brittleness. G. V. Uzhik and A. A. Zuikova. (*Metall. Obra. Met.*, 1956, (4), 26–34). The mechanical origin of temper brittleness resides mainly in the different capacities of steels in the brittle and plastic conditions to form initial plastic deformations under conditions arising after the beginning of the fracture i.e. after the occurrence of fissures, and in the different capacities of the material in the two conditions mentioned to show resistance to the fracture already started.—L. H.

Tendency of Metals to Cold Brittleness Under Static Loads. G. I. Pogodin-Alekseev. (*Metallov. Obra. Met.*, 1955, (2), 8–14). On lowering the experimental temperature beyond a certain point, an increase in the plastic deformation and a decrease in the load can be observed. The fall in the concentration of the load is a sign of the embrittling process. Hence the upper threshhold of cold brittleness must be defined by the beginning of the fall in the magnitude of the load.—L. H.

On the Origin of Reversible Temper Brittleness in Structural Steels. S. F. Yur'ev. (*Metall. Obra. Met.*, 1956, (10), 37–51). Tempering hardness of the second order appears as a consequence of carbide changes in the adsorption layers enriched by elements and admixtures in the austenitic condition. This condition maintains itself in slow cooling after tempering. An increase in the duration of the process or in temperature results in diffusion-relaxation, "closing up" of empty spaces and defects of structure along the austenite boundaries.—L. H.

Investigation in Non-Reversible Temper-Brittleness of Alloy Ferrite. M. M. Shteinberg. V. D. Sadovskii and A. V. Demakova. (*Metall. Obra. Met.*, 1956, (4), 21–25). Alloy ferrite with 0·01%–0·02% C is susceptible to non-reversible brittleness occurring in the temperature range in which structural steels are tempered. It occurs when carbon combines to form carbides of titanium and the steel loses its capacity for hardening. This susceptibility may be observed not only in the absence of residual austenite but also in the absence of the martensite phase.—L. H.

Investigation of the Influence of Cold-Hardening on Cold-Brittleness in Steels and Welds. B. F. Lebedev. (*Avtom. Svarka*, 1958, **11**, (1), 28–31). The experimental study was undertaken to establish the influence of slight deformation by bending during the manufacture of containers on the cold brittleness of steels and welds. The manufacture of these containers is carried out by a single-stage mounting on which the whole width is welded on one side and the plate is then immediately bent on a roll of 2·5 m diameter. Experimental results covering various fluxes and methods of welding are set out and the findings analysed and discussed.—L. H.

Contribution to the Study of Brittleness in Steels, Having an Alpha Structure, by Hydrogen Introduced in the Cold and the Diffusion of Hydrogen in the Same Steels. P. Amiot. (*Pub. Inst. Rech. Sidér.*, 1957, Series A, No. 158, April, 1–80). A comprehensive series of tests on a wide range of steels having an α-structure are reported. H_2 is introduced into the specimens by electrolysis and tests have been carried out at temperatures down to — 196° C. H_2 introduced into steels reduces the capacity for plastic deformation. The effect of prestressing the sample prior to H_2 being introduced is to increase the subsequent brittleness. Apparatus is described for measuring the diffusion of H_2 in steel. (67 references).—B. G. B.

On the Tendency of Low-Carbon Steel to Brittle Fracture After Electrolytic Iron Plating. B. P. Sinyutin. (*Metall. Obra. Met.*, 1956, (1), 45–46). As a consequence of hydrogen formation during the preparation for electrolytic iron plating and during the operation itself, the impact viscosity of steel is appreciably lowered. An increase in the acidity of the electrolyte increases the tendency of steel to brittle fracture. Keeping iron plated steel for 6 months does not eliminate the influence of hydrogen on the impact resistance of the steel. Tempering at 350° restores the impact strength.—L. H.

The Influence of Silicon and Phosphorus on the Brittleness of Malleable Irons. P. Bastien, P. Azou and C. Winter. (*Fonderie*, 1957, Aug., 343–352). The authors describe tests and results for establishing the causes of failure in the galvanized surface of malleable irons. Certain chemical compositions prevent these failures. A general theory could not be postulated.

Use of Stepped Specimens for Inspecting Steel for Hair Cracks. I. V. Samolov. (*Stal'*, 1958, (3), 244–245). The process is useful only for certain grades of steel. Measurements on rods 2 m long in 10 parts were made by magnetic defectoscope after sand-blasting, after grinding off ½ mm, visually after pickling in hot HCl and the same with stepped specimens and magnetically with stepped specimens.—R. S.

Fractures of Brittle Character in Suspension Springs of Vehicles. A. A. Arantes, M. L. Pinkuss and F. P. Canto. (*Bol. A.B.M.*, 1957, **13**, Oct., 319–327). [In Portuguese]. The study of a large number of spring failures has shown that poor road surfaces are the main cause, but the use of high carbon steels aggravates the problem. Steels with better mechanical properties should be used, but a partial solution would be to avoid the temper-brittle range in heat-treatment and to pre-deform. (10 references).—P. S.

Changes of Mechanical Properties of Low Carbon Steel in Relation to the Conditions of Cooling After Heating. I. A. Nenaezdnikov. (*Vestnik Machin.*, 1954, (8), 52). To prevent cracking, rolls and sheet billets should not be subjected to heating at 1100–1200° C and quenched in water at 20° C. It is recommended to heat them to a maximum of 900° C and cool in air.—S. I. T.

Relationship Between Subzero and Hot Brittleness in 18–8 Austenite Stainless Steels. A. Gueussier and R. Castro. (*Rev. Mét.*, 1958, **55**, Feb., 107–122). The carbide precipitations occurring in austenitic steels by sensitization are embrittling at very low temperatures and shift the impact-temperature curve towards higher temperatures. The character of the precipitations when the steel contains Ti or Nb are shown. An embrittlement at elevated temperatures is also observed. The precipitations which are responsible may occur during the deformation itself; the kinetics depending on the analysis and previous treatment.

Naval Architect's Problems with Ship Plate. D. P. Brown. (*Reg. Tech. Meet. A.I.S.I.*, 1957, 591–612). Brittle fracture and the results of impact and other tests are discussed.

Lloyd's Survey of Brittle Fracture. (*Engineering*, 1958, **185**, Apr. 18, 497–498). A brief review of failures in welded ships with an account of recent findings and recommendations is given. Requirements for steel properties and control and testing of notch toughness are noted.

Critical Range for Brittleness in Steels for the Electrical Industry. N. I. Lapkin, G. I. Shubin and S. I. Doroshek. (*Fiz. Met. i Metalloved.*, 1957, **4**, (3), 478–482). The critical range for brittleness in transformer grade steels containing 1 to 5·8% Si varies from — 80 to + 250° C depending on the Si content. The transition from brittle to ductile fracture at high temperature was smooth throughout a comparatively wide temperature range. The type of deformation, direction of rolling and heat treatment exerted a marked influence on sensitivity to brittleness. Higher Si contents retarded the development of blue brittleness.—R. S.

The Coefficient of Dry Friction of Metals. R. Takagi and Y. Tsuya. (*J. Mech. Lab.*, 1958, **12**, Jan., 12–17). [In Japanese]. The preparation of clean surfaces is described with elimination of the oxide films. Experiments on Cu, Fe, Ni, Mo, W and Sn were made. Figures for iron on iron are given.

The Wear of Machine-Tool Castings. M. Csch and A. Gaál. (*Koh. Lapok*, 1957, **12**, July, Öntöde, 163–171). Reference is made to German, English, American and Russian papers about the influence of various factors (surface, structure, graphite, phosphorus, Brinell hardness etc.) on the wear of machine tool castings. The machining, running-in, and lubrication are the most important factors in determining wear resistance.—P. K.

Investigation of the Resistance to Wear of Alloys TZOK4 and VK2. A. B. Novikov. (*Stanki Ins.*, 1958, (1) 24–25). From laboratory experiments and from investigations made under conditions of production it has been established that alloy VK2 gives better results for the preparation of inoculated cast iron. Its hardness is higher and its rate of wear lower than the other alloy.—L. H.

The Relation Between the Wear-Resistance of Metals in Friction against an Abrasive Surface and their Hardness. M. M. Khrushchov and M. A. Babichev. (*Vestnik Machin.*, 1954, (9), 3–9). The results of experiments on the correlation between the resistance to abrasion and the indentation hardness of pure metals and steels shows that (1) metals not thermally treated show a linear relationship between resistance to abrasion ϵ and hardness (H) with a high coefficient of proportionality (b), $\epsilon = bH$. (2) the linear function of quenched and annealed steels is shown by a line at a lower inclination, (3) the work hardened steels give a line parallel to the H-axis of the ϵ/H diagram. A new dimensionless parameter is proposed to express the resistance of steels in relation to their thermal treatment.—S. I. T.

Improving the Antifriction Characteristics of Steels by Means of Chlorination. Yu. M. Vinogradov and N. S. Dombrovskaya. (*Izvest. Akad. Nauk, Otdel. Tekh.*, 1958, (1), 128–130). The effects of chlorination at various temperatures are described and the results obtained are discussed.

Influence of the Microstructure on the Resistance of Carbon Steels to Abrasive Deterioration. V. M. Guterman and M. M. Tenenbaum. (*Metall. Obra. Met.*, 1956, (11), 15–23). The hardness of steel is not a sufficient criterion for the computation of its resistance to wear. The resistances of pearlite, sorbite and troostite are determined by the degree of dispersion of the cementite particles; the finer the structure for a given chemical composition, the higher the resistance of the steel. The resistance of martensite is determined by its content of carbon, the greater the carbon content, the higher the resistance.

Strength and Wear-Resistance of Roller Bearing Components. S. V. Pinegin. (*Vestnik Mashin.*, 1958, (3), 8–11). The article considers the conditions under which these components operate and examines the means of minimizing fatigue failures, abrasion, seizing etc.—L. H.

Testing Machine for Bearings and a Few Results Obtained by It With Bearings of Spheroidal Graphite Iron with Pearlitic-Ferritic Structure. A. Chisu, G. Muncaciu and L. Peter. (*Met. Constr. Masini*, 1957, (12), 30–34). [In Rumanian]. The development of nodular graphite iron production and use has made it necessary to introduce special specifications and standards for this material and the Rumanian Railway Workshops, with the help of the Science Institute, have elaborated a new testing machine. The article describes this machine, its construction and action, and gives some examples of its use.

Magnetic Particle Inspection of Grey Iron Castings. A. Lindgren. (*Foundry*, 1958, **86**, Feb., 178–179, 181, 183, 184). Magnetic particle crack detection is briefly described and examples are given of typical defects which can be revealed by the technique. The usefulness of this method of inspection is stressed.

Ferromagnetism. L. M. Bates. (*Met. Corr. Ind.*, 1957, Oct., 382–396). The author describes new techniques and results in the investigation of ferromagnetic phenomena. Crystallographic data and experiments are discussed as well as studies with the electron microscope. (24 references).—B. P.

Some New Achievements in the Field of Magnetic Investigations at Tokyo. R. Kubo. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (8), 1197–1204). The work described deals with the magnetic susceptibility of transition metals near the melting point, tempering in a magnetic field and the anisotropy of annealed Co–Fe ferrites.—S. K.

Dynamics of the Domain Structure in Silicon Iron Crystals. L. V. Kirenskii, V. D. Dylgerov and M. K. Savchenko. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (8), 1168–1169). The results are presented of a study of powder figures during continuous change of elastic stresses and magnetic field. Direct observations were also made of the rotation process by the powder-figures method. Single crystals of silicon-iron whose (110) plane coincided with the observed surface were used.—S. K.

Nature of the Boundaries of Ferromagnetic Regions. K. P. Bin. (*Izvest. Akad. Nauk. Seriya Fiz.*, 1957, **21**, (8), 1183). This is an abstract of a report describing work in the U.S.A. on the accurate measurement of the surface energy of ferromagnetic domain boundaries, by a new method.—S. K.

Magnetic Material Testing of Stainless Steel by Means of Electron Beams. S. Yamaguchi. (*Z. Metallk.*, 1958, **49**, Mar., 156–157). It is difficult to detect by crystallographic methods ferrite contained in austenite, due to the similarity in the lattice plane distances of both types of crystal. The conditions are described under which these substances can be analysed magnetically by the use of electron beams.—L. D. H.

Thermal Effects Accompanying Magnetization Processes. L. F. Bates. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (8), 1184–1196). The author describes recently theoretical and experimental work in the U.K. on thermal effects on magnetization.—S. K.

Anisotropic Magnetic Cores. P. Denesh. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (8), 1205–1212). The author discusses possible ways of improving the performance of cores by increasing their permeability without increasing losses.—S. K.

The Relationship between Particle Size, Depth of the Magnetically Inhomogeneous, Surface Layer, Coercive Force, and Saturation Magnetisation of Carbonyl Iron and Magnetite Powders. K. Torkar, O. Scheikl and H. Egghart. (*Arch. Eisenhüt.*, 1958 **29**, Feb., 139–146). The results of tests with carbonyl iron powder with a particle size between 0·0117 and 0·1 μ, and magnetite powder with a particle size between 1 and 827 μ indicate that the maxima of the coercive force are determined by crystal anisotrophy and not by the shape- or stress-anisotropy of the particles: for carbonyl iron powder they are about 160 Oe, for magnetite powder 110–130 Oe.

Ferromagnetic Iron Oxides. J. Vavra. (*Chem. Listy*, 1958, **52**, (4), 573–577).

Investigation of Irreversible Supermagnetization Jumps in Ferromagnetics. V. F. Ivlev, V. L. Il'yushenko and L. I. Aseeva. (*Izvest. Akad, Nauk Seriya Fiz.*, 1957, **21**, (9), 1250–1254). This work aimed at establishing whether the previously discovered effect that both number and amplitude of supermagnetization jumps fall with rising temperature, another aim being the investigation of the dependence of these parameters on the crystallographic direction and temperature. Three materials were studied: iron wire (99·93% Fe) 0·56 mm dia., 4 cm long, annealed and not annealed, iron wire (99·59% Fe), 0·20 mm dia. and 4 cm long annealed and not annealed; and a single crystal of transformer iron (3·4% Si).—S. K.

On the Structure of a Family of Symmetrical Hysteresis Loops of Ferromagnetics. R. I. Yanus and V. P. Kartashov. (*Izvest. Akad. Nauk, Seriya Fiz.*, 1957, **21**, (9), 1255–1261). The authors discuss the nature of families of symmetrical hysteresis loops obtained with ferromagnetics and describe their own work with pointed specimens of 3% Si cold-rolled iron. Their measurements were carried out using conventional methods and the article deals mainly with the treatment of the results.

Investigation of Hysteresis Losses in Rotating Magnetic Fields in a Single Crystal of Magnetite Before and After Phase Transformation. N. L. Bryukhatov. (*Izvest. Akad. Nauk, Seriya Fiz.*, 1957, **21**, (9), 1268–1274). The investigation described was carried out on a single crystal of Ural magnetite, shaped into a sphere 10·4 mm in diameter. By measuring the mechanical moments with a magnetic structural dynamometer the magnetic energy anisotropy of the crystal was studied and hysteresis losses in rotating fields were determined. Measurements were made at room temperature and at liquid nitrogen temperature in fields of 10 to 10,000 Oe. The mechanical moment curves were obtained for the (100) plane. The unusual rise of hysteresis in strong rotating fields observed is discussed in terms of the structure.—S. K.

Influence of Elastic Stresses and Thermomechanical Working on the Magnetic Properties of High-Coercivity Alloys. Ya. S. Shur, M. G. Luzhinskaya and L. A. Shubina. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (9), 1275–1279). The authors describe their work with high-coercivity alloys of the systems Fe–Co–V (8, 12 and 14% V and 52% Co) and Fe–Mn (15% Mn), chosen for their high elastic limit. The specimens used were wires 0·1–3·0 mm in diameter and 50–80 mm long, obtained with reductions of 75–98%. The specimens were subjected to tempering at temperatures up to 700° C, tensile stresses of up to 90 kg/sq.mm being applied for the thermomechanical treatment. Both elastic stresses and thermomechanical treatment were found to have a substantial effect on the magnetic properties.—S. K.

Fall in Magnetic Permeability in Silicon Iron. Yu. S. Vail'. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (9), 1281–1287). In this work, the fall in the magnetic permeability of silicon-iron was studied over a wide range of time, temperature and magnetic field strength. Industrial-transformer core iron was used, mainly type KhVP in the form of 0·08 mm thick ribbon, but also ordinary 3·5-% Si steel (0·35 mm thick) and Armco-iron. The dependence of the fall of permeability on the temperature, the influence of the external field strength, the fall in permeability on applying and removing elastic stresses and the influence of cold working and heat treatment were studied. The falls observed amounted in some cases to 70% and the reasons for and significance of this effect are discussed.—S. K.

Measurement of the Initial Permeability of Ferromagnetics in the Centimetre-Wave Region. G. S. San'yal. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (9), 1302–1309). The author outlines some theories of the frequency dispersion of permeability and describes completed and planned work at the Indian Institute of Technology in this field.—S. K.

Magnetic Moments and Curie Constants of Ferromagnetic Alloys. F. M. Gal'perin. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (9), 1323–1326). The author proposes empirical relations for the atomic magnetic moments, Curie points and other properties of ferromagnetic alloys similar to those previously proposed by him for pure ferromagnetic metals. He shows that the relations agree satisfactorily with experiment for Fe–Cr and Fe–Ni alloys.—S. K.

Investigation of the Magnetic Susceptibility of Solid Solutions Based on Iron and Nickel. V. V. Parfenov. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (9), 1327–1333). The study of the magnetic susceptibility of solid solutions in strong magnetic fields at various temperatures is described. The materials studied were the whole range of Fe–Ni, Fe–Si with up to 6% Si and Ni–Cu with up to 10% Cu. The results are discussed in terms of a general equation.—S. K.

Influence of Structural Peculiarities of Ferromagnetics on the Temperature Course of Spontaneous Magnetization. K. P. Belov and A. N. Goryaga. (*Izvest. Akad. Nauk Seriya Fiz.*, 1957, **21**, (8), 1038–1406). The results are given of an experimental study of curves of true magnetization near the Curie point for certain Ni alloys, including two with 64 and 65% Fe. For these, the nature of the variation of spontaneous magnetization with temperature near the Curie point depended on the heat treatment. The anomalous form of these curves the authors attribute to the fact that, in invar-type alloys, ferromagnetism is due to the mutual interaction of atoms situated not only in the first but also in other coordination spheres, this leading to a blurring of the ferromagnetic transformation.—S. K.

METALLOGRAPHY

Some Experiences with the No. 1900 AB Automet Polisher Attachment. R. L. Anderson. (*AB Metal Digest*, 1958, **4**, July, 3–9).

Investigation into the Radioactivity of Non-metallic Inclusions in Steels by Electrolysis. M. I. Tsekhanskii, N. I. Shishkina and K. B. Khusnoyarov. (*Zavods. Lab.*, 1957, (12), 1440–1442). [In Russian]. During the elimination of non-metallic inclusions containing radioactive isotopes of calcium, it was found that the proposition that non-metallic inclusions forming in the process of the interaction of the liquid steel with the refractory material are a very small proportion of the normal content is doubtful.—L. H.

Micro-Constituents in Steels: Their Electrolytic Isolation and X-ray Study. K. W. Andrews and H. Hughes. (*Iron Steel*, 1958, **31**, Feb., 43–50). The authors describe electrolytic methods for the isolation of micro-constituents in steel, and their subsequent examination, particularly by X-ray analysis, in order to identify them and provide information on such factors as particle size and shape, solid solution effects, and lattice parameters. The use of the results in explaining or interpreting the properties and behaviour of steels is described, particular reference being made to tempered martensites, carbides in low carbon steels, steels containing the sigma phase, the behaviour of a Cr–Mo–Ti steel, and carbide reactions and other changes in a Cr–Mo steel.—G. F.

Direct Observations of Non-Metallic Inclusions in Steel with an Electron Microscope. T. Akutagawa, I. Uchiyama and A. Fukami. (*Tetsu-to-Hagane*, 1957, **43**, Nov., 1222–1228). [In Japanese]. The extraction replica technique used an evaporated carbon film. New techniques were employed for cleaning the surface of the etched specimen, evaporation and separation. TiN, FeS, SiO_2, MnS and other inclusions were examined. (16 references.)—K. E. J.

A Rapid Method of Isolating the Carbide Phase in Steels. O. S. Spiridonova and T. I. Bezuglova. (*Zavods. Lab.*, 1957, (12), 1412–1413). [In Russian]. The method consists of introducing into the electrolyte (N KCl + 5 g. citric acid/l) the electrolytic solution, however the conditions of electrolysis and the subsequent treatment of the precipitation of carbide are modified, resulting in an appreciable speeding up and simplification of the method of isolating the carbides.—L. H.

Looking Inside Stainless Ingots. J. C. Fulton and R. H. Henke. (*Steel*, 1958, **142**, Feb. 17, 132–134). Sections of Cr and Cr–Ni ingots were examined. Macrosegregation was not serious, but microsegregation was present in both alloys. In the 17% Cr alloy a carbon depleted rim was found adjacent to the carbide envelopes around areas that were originally all austenite; this type of segregation is harmful to strip products and its appreciation influences rolling practice. The small ferrite plus carbide islands found in the Cr–Ni grade can be controlled by the chemistry and high temperature heating of the mill products.—D. L. C. F.

Studies on the Formation of Inclusions during Deoxidation with Silicon. W. A. Fischer and M. Wahlster. (*Arch. Eisenhüt.*, 1958, **29**, Jan., 1–9). The samples were melted down in silica, magnesia, corundum, and lime crucibles, and left to stand exposed to the atmosphere until saturated with oxygen. Si was then added. Samples taken from the melts before and after Si addition were investigated by metallographic methods and non-metallic inclusions were separated electrochemically.—L. J. L.

Influence of the Chemical Composition of Deoxidiser Fe–Mn–Si–Al on the Quantity and Chemical Composition of Non-metallic Inclusions in Steel. J. Foryst, W. A. Mczedliszwili and A. M. Samarin. (*Prace Inst. Ministerstwa Hutnictwa*, 1957, **9**, (4), 151–160). [In Polish]. The effect of variable content of Mn, Si and Al in the composition of Fe–Mn–Si–Al deoxidizer on the quantity and chemical composition of inclusion in steel was investigated. It was found that with increase of Mn in the deoxidizing alloy the proportion of non-metallic inclusions rapidly decreased. When investigating the effect of Al after a preliminary deoxidation of the steel by Mn–Si it was found that after addition of Al the inclusions remaining in the steel undergo the following changes: reduction to half of the SiO_2 inclusions, considerable increase of Al_2O_3 and a slight increase of FeO.

The Structural Stability of 12% Cr–W–Mo–V Steels. J. Koutský, J. Neid and J. Ježek. (*Hutn. Listy*, 1958, **13**, (3), 199–205). [In Czech]. Two 11·7% Cr steels were studied, one containing 0·91% Ni and 0·8% W; the other 0·18% Ni and 3·9% W. The Mo and V contents of both were equal, amounting to

0·63 and 0·26% respectively. Micrography, and electron diffraction of carbidic and other phases separated after various heat-treatments, and creep tests, showed that (*a*) the higher W content leads to structural heterogeneity in the heat-treated state; the structure is unstable while the steel creeps in the range 500–680° C, the delta ferrite decomposing and thus inducing a higher creep resistance. (*b*) This creep resistance begins to decline eventually due to over-ageing. The creep limit of the low-W steel at 600° C is 7 kg/mm² for a 100,000 h life; under a load of 8 kg/mm² the creep rate is 9·5 .10⁻⁵% per h. Thd high-W steel has a creep limit of 15 kg/mm- and a creep rate of 1·8 . 10⁻⁵% per h under similar conditions. An increase of the amount of delta iron cannot therefore be regarded as damaging to the creep resistance. (*c*) Brittleness is however increased by delta iron. (*d*) Certain unexpected phases were disclosed by X-ray and electron-diffraction experiments on the carbides isolated from the steels with decomposed delta ferrite, but their exact composition could not be ascertained.—P. F.

Study on Carbides in Commercial Steels by Electrolytic Isolation. IV. On Carbides in Low W-Cr Cutting-Tool Steels. T. Sato, T. Nishizawa and M. Ohashi. (*Tetsu-to-Hagane*, 1958, **44**, Feb., 146–150). [In Japanese]. The principal carbide in the annealed structure was $M_{23}C_6$ (κ-carbide), but some cementite containing W and Cr (θ-carbide) also appeared in the low-W steels. With tempering, ε-carbide precipitated in the first stage, and θ-carbide in the third; κ-carbide appeared with tempering above 650° C. In the fourth stage an enrichment of W and especially Cr into the carbides occurred. In a Cr-free steel, κ-carbide was decomposed by annealing, and by heating to quenching temperature; WC and ε-carbide were formed.—K. E. J.

Electrolytic Isolation of Martensite and Austenite from Hardened Steels. V. D. Zelenova. (*Zavods. Lab.*, 1958, **24**, (1), 60–62). Martensite was isolated by anodic solution from steel Y10, hardened from 900, 1100 and 1200°. The electrolyte was a N solution of KCl with the addition of citric acid. Austenite was similarly isolated from steels X12M, X12F and E169, using a modified technique.

The Structure and Composition of Carbide in Low-Temperature Tempered Steel. Yu. A. Skakov, I. N. Chernikova and A. V. Sharshatkina. (*Doklady A.N.*, 1958, **118**, (2), 284–285). Steel of composition 0·58%C, 0·10%Mn, 0·08%Si, 0·033%S, 0·05%P and 0·017%N was quenched in water and tempered at 100°, 200° and 400° C for 1 h. After electrolytic etching, samples were subjected to "reflex" electronography. The sample tempered at 100° did not produce any effects, the electrograms of the other two samples suggest that the carbide of a low-temperature tempered steel has hexagonal close-packing with $a = 2·73$ and $c = 4·34$ Å. Calculations for Fe_2C give $a = 2·93$, $c = 4·62$ Å. Interpolation suggests that ε-carbide has the formula Fe_4C.—S. I. T.

Magnetic Separation of Structural Constituents Isolated Electrolytically from Metals. W. Koch and H. Sundermann. (**Arch. Eisenhütt.*, 1958, **29**, Apr., 219–224). A magnetic separating apparatus is described for separating strongly magnetic and slightly or non-magnetic constituents of a mixed isolate. The constituents are set in violent motion in a varying magnetic field, and thereby separated. Illustrative examples of the use of the apparatus are given.

On the Effect of Elastic Strain and of Alloy Content on the Tendency of Carbon or Nitrogen to Separate in α-Iron. H. J. Seemann and M. Siol. (*Acta Met.*, 1958, **6**, Feb., 127–129). The properties of τ, the time constant for the separation of supersaturated solutions of C or N to separate from iron are discussed in terms of diffusion constant, SNOEK-damping maximum and other factors. The relation to C + P is also shown.

Grain Boundary Segregation of Phosphorus in an Iron-Phosphorus Alloy and the Effect on Mechanical Properties. M. C. Inman and H. R. Tipler. (*Acta Met.*, 1958, **6**, Feb., 73–84). Direct evidence of grain boundary segregation of phosphorus in an alloy containing 0·09% P was obtained by a radioactive tracer technique. The concentration in the boundary region is 50 × that at the centre of the grain. The degree of intergranular failure was related to the amount of phosphorus in a grain boundary layer ~ 1000 Å in thickness

The Isolation of Sulphide Inclusions and Relationships Between the Properties of Steel and Inclusions. K. Born. (**Arch. Eisenhütt.*, 1958, **29**, Mar., 179–187). It is shown, in the case of killed steels, that an almost complete isolation of sulphide inclusions can be achieved by removing carbon from the anode samples in a current of hydrogen at 870° C, dissolving residual cementite by quenching from 700° C, electrolysis, followed by magnetic separation and a treatment with alcoholic iodine solution. 20 steels were examined, and their properties discussed in relation to the sulphide inclusions.

A New Type of Grain Boundary Precipitate Observed in Cast Steel. I. S. Brammar, R. W. K. Honeycombe and R. G. Ward. (*Acta Met.*, 1958, **6**, Feb., 134–135). The fracture surfaces of cast steel containing 0·13%C, 4·0%Ni, 1·38%Cr, 0·49%Mn, 0·015%S were examined with the carbon replica technique and by autoradiography. A plate-like precipitate 0·1 μ thick, probably of α-MnS, was detected at grain boundaries.—A. D. H.

The Effect of Re-granulation on Grain Size and Structure of Ferrite and Austenite in an Unalloyed Steel with 0·15% C. H. Borchers and G. Boxhorn. (*Arch. Eisenhütt*, 1958, **29**, Jan., 47–56). Grain refinement due to simple and repeated re-granulation is discussed; a comparison is made between ferrite and austenite structure; observations of structure changes in the temperature range between Ac_1 and Ac_3 are reported.

Grain Boundaries in Commercially Manufactured Metallic Substances. H.-K. Görlich. (*Radex-Rund.*, 1958, Jan., 31–35). A review of boundary formation during crystallization and the occurrence of inclusions, flaws, and dislocations is given. The possibilities of electron microscopy are considered. A method of investigation is described and preliminary results are presented.

New Method of Finding the Grain-Size of Iron Alloys. F. Boda. (*Koh. Lapok*, 1957, **12**, June, 246–249). A polished micro-section was austenized for 30 min in a pure H_2 or sometimes in a N_2 atmosphere and quickly cooled. The austenite boundaries then became visible.—P. K.

On the Martensite Crystal. Z. Nishiyama and K. Shimizu. (*Acta Met.*, 1958, **6**, Feb., 125–127). Electron microscopical studies of a Fe–30·64%Ni alloy suggest that the martensite plate is a single crystal and that the mid-rib region has almost the same orientation as the ground but with more lattice imperfection.—A. D. H.

A Study on the Method for Revealing the Austenite Grain Size in Steel. A. Adachi, K. Mizukawa and N. Hiraoka. (*Tetsu-to-Hagane*, 1957, **43**, Nov., 1229–1233). [In Japanese]. Carburizing, graphite, quenching, double-quenching, oxidizing and other methods were compared. The easiest for comparing grain size is the metal diffusion method. If Pb is used for this, the grain size can be determined without interference from alloying elements in the steel.—E. E. J.

Studies on Duplex-Grain Structures of Austenite. I. Effect of Duplex-Grain Structures on Properties of Steel. 1. Y. Masuko. (*Tetsu-toHagane*, 1957, **43**, Dec., 1307–1312). [In Japauese]. Results are given for carbon steels containing 0·30, 0·70 and 1·00% C and Ni–C–Mo case-hardening steels. "Uniform" and "non-uniform" duplex-grain structures are distinguished, and their occurrence is compared with results from McQuaid-Ehn tests. In general steels showing non-uniform duplex grains in those tests are undesirable, while those having a uniform duplex-grain structure have almost the same properties of strength and ductility in heat-treatment as fine-grained steels.—K. E. J.

The Growth of Austenite Grains of Steel 45 on Heating by a High-Frequency Current. E. N. Druzhinina. (*Vestnik Machin.* 1954, (11), 59–60). The growth of austenite grains in the process of the normalization of steel depends not only on the temperature but also on the rate of heating. For each rate of heating there exists a rather narrow range of optimum temperature. Detailed descriptions of textures of steels undergoing various thermal treatments are given.—S. I. T.

Directional Properties Caused by Forging and Dimension-Change Rate due to Heat-treatment with Different Heavy Sections of Tool Steel. S. Koshiba and H. Homma. (*Tetsu-to-Hagane*, 1957, **43**, Dec., 1303–1307). [In Japanese]. Data are given for Cr cold die steel, Cr–W–V hot die steel and Mn–Cr–W gauge steel on the differences in change of dimensions after heat treatment. The changes in length and diameter are greater in the direction of forging than in the transverse direction, except for the length change of the Mn–Cr–W steel.—K. E. J.

Pearlite and Intermediate Stage Structures in Three Carbon Steels. S. Modin. (*Neue Hütte*, 1958, **3**, April, 235–238). The structure of two sub-eutectoid steels after isothermal austenite transformation is compared with the corresponding structure of a eutectoid steel. The ferrite was found to promote nucleus formation in the intermediate stage transformation. It is suggested that the ferrite segregated from the austenite has a low carbon content, and that carbon enrichment occurs in the austenite during ferrite segregation.

The Pearlite Transformation in Alloy Steels. R. I. Entin. (*Metall. Obra. Met.*, 1956, (10), 20–28). The findings of this experimental work show that the disintegration of austenite in the pearlite region is related to the distribution of the alloy elements in the austenite and to the direct formation of special carbides from austenite over a range of composition. The conditions of the formation of this carbide phase can be calculated, and also explained by thermodynamical and kinetic considerations.—L. H.

Methods of Investigating the Mechanism of the Transformation of Pearlite into Austenite with High Rates of Heating. G. T. Fomin. (*Zavods. Lab.*, 1958, **24**, (1), 56–57). An investigation is described into dilatometric methods of examining the transformation of pearlite into austenite at different rates of heating. The heating rate was varied by a preliminary heating of the furnace to different temperatures.—L. D. H.

The Effect of Magnesium on the Formation of Graphite in Cast Iron. K. I. Vascenko and R. P. Todorov. (*Slevarenstvi*, 1958, **6**, March, 65–71). On the basis of the experiments (increase in volume prior to solidification shrinkage, cooling curves, micrographs, heat treatment at various temperatures, hot-working and quenching in water, determination of free carbon and rate of cementite decomposition), it is possible to conclude that the mechanism of graphite formation in grey iron is basically different from that in ductile irons. In the former, graphite is formed predominately by direct crystallization from the liquidus, whereas in ductile irons a marked proportion is formed by cementite decomposition. This conclusion is confirmed by the fact that in ductile irons the increase in volume before shrinkage is extensive, and by various other factors including structural changes after plastic deformation at temperatures around the eutectic point. The active affect of Mg is not restricted to delaying the formation of graphite, but changes the nature of its formation and structure. Spheroidal graphite is formed only with sufficiently high Mg content (up to 0·082% was used) which increases delay in its appearance. The proportion of graphite can be varied within wide limits when formed by either mechanism.

Variation of Electric Resistance of Cast Iron in Connection with the Formation of Graphite in the Iron. V. P. Chernobrovkin. (*Fiz. Met. i. Metalloved.*, 1957, **4**, (3), 564–566). Graphite forms in normal grey cast iron during solidification. The change in the electric resistance of iron during solidification depends

on the form and amount of the graphite produced.—R. S.

Contributions to the Study of the Graphitization Process in Nodular Cast Iron. K. I. Vashtshenko and L. Sofroni. (*Rev. Mét. Bucarest*, 1957, (2), 51–81). [In English]. Volume changes are studied in addition to cooling curves and microstructures. The mechanism is discussed at length and various hypotheses are considered. (28 references).

Some Problems of the Kinetics of Isothermal Transformations of Spheroidal Graphite Iron in the Solid State: Graphitization, Formation of Austenite and Decompostion of Pearlite. D. Rasceev. (*Acad. Romine Met.*, 1957, **2**, (3), 241–264). A commercial iron was used and hardness and microstructure were observed. Diagrams for the transformation are given and from these conditions for annealing, graphitization, normalization and other thermal treatments can be found.

Change of Length During Transformation of Iron Under Stress. M. de Jong and G. W. Rathenau. (*Nature*, 1958, **181**, May 17, 1396–1397). Pure Fe was heated through the transformation temperature at 910° and change of length determined for an α–γ transformation, γ–α transformation and for an α–γ–α cycle as functions of stress. Findings are discussed and will be published elsewhere.

Carbide Transformation During Tempering of Steel. V. G. Permyakov and M. V. Belous. (*Fiz. Met. i Metalloved.*, 1957, **4**, (3), 490–499). The relationships between changes in magnetizability of steel during the process of tertiary transformation during tempering, the composition of the low temperature carbide and its specific magnetizability are discussed.—R. S.

The Effect of Heating Rate on the Properties of Heat-Treated Stainless Steel. I. S. Sakui and T. Mori. (*Tetsu-to-Hagane*, 1958, **44**, Feb., 136–142). [In Japanese]. Cold-rolled 18–8 steel was heated at rates of 10^4 °C/sec and 10 °C/min. The softening temperature was far higher with rapid heating, but the temperature difference decreased with reduction of thickness of specimen. The α-phase produced by cold rolling began to disappear at about 500° C in slow heating and 600° C in rapid heating. Rapid heating produced a very fine grain size after recrystallization. Carbides precipitated at 600–900° C with slow heating, but not at all with fast. Corrosion tendency followed carbide precipitation behaviour.—K. E. J.

The Isothermal Time Temperature Transformation Diagram of a Domestic 25CrMo4 Steel With The Corresponding Surface-Quench Hardness Curve. B. I. Božic and Z. Varšek. (*Documenta Chemica Yugoslavica*, 1957, **22**, (3), 149–160). Microstructure is also described showing slow martensite formation on the surface and C and Fe diffusion and relationships between austenite, ferrite and bainite are discussed. Vickers hardnesses are also recorded.

Influence of Electric Heating on the Phase Transformation of Carbon and Chromium Steels. I. E. Kontorovich and A. G. Vinitskii. (*Metallov. Obra. Met.*, 1955, (2), 21–25). The increase in the rate of electric heating leads to an uninterrupted increase of the transformation temperature of pearlite into austenite. This transformation occurs at lower temperature than the increase in the dispersion of structure.—L. H.

Phase Transformation in Steels under High-Frequency Electric Heating. A. P. Gulyaev and V. M. Zalkin. (*Metallov. Obra. Met.*, 1955, (2), 15–20). These investigations give diagrammatically the results of the kinetics of transformation of pearlite into austenite: (*a*) in continuous heating; (*b*) in heating at the rate of 10, 60, 160 and 350° per sec. (*c*) comparison between the kinetic and thermal curves at various temperatures; (*d*) the kinetics of isothermal transformation at 730, 751, 745, 755 and 775° at the rate of 60°/sec.

On a Fringe-Shaped Eutectoid in the Transformation Structure of Low- and Medium-Alloy Temperature-Resistant Steels. R. Pusch and H.-J. Schüller. (*Arch. Eisenhütt.*, 1958, **29**, Jan., 65–72). Results are reported of a detailed investigation of the carbide-containing structures that separate the ferrite from the martensite, intermediate, or pearlite areas found from the residual austenite.—L. J. L.

Investigation of the Third Transformation During the Tempering of Steel. A. P. Gulyaev and N. I. Burova. (*Metallov. Obra. Met.*, 1955, (1), 40–46). The appearance of the third transformation in non-carbon, Fe–Mn alloys (0·04% C and 4·5% Mn) and in technical iron in which the carbide phase is absent, proves that the third transformation is not dependent on the carbide transformation. Cooling in liquid nitrogen shows an increase in the third transformation even in those steels in which, after hardening, residual austenite is absent. The main process in the third transformation is the relieving of stresses of the 2nd order.—L. H.

On Carbide Reactions in Mo-Steels. J. Čadek, B. Fleischer and K. Mazanec. (*Hutn. Listy*, 1958, **13**, (3), 206–212). [In Czech]. Carbide reactions occurring in steels containing 0·35% C with 2·1, 3·8 or 5·0% Mo respectively, and 0·19% C with 5·1% Mo were studied at 650° C. The results showed that (*a*) the isothermal decomposition of the austenite is connected with the formation of a eutectoid, the carbide component of which is the metastable Mo_2C. The decomposition of the austenite is completed by the formation of this eutectoid only in the 0·35% C and 5·0% Mo steel. In steels containing less Mo the formation of granular Mo_2C is followed by the formation of a lamellar eutectoid with a metastable carbide component $M_{23}C_6$. (M here denoting "metal"). In the 0·19% C and 5·1% Mo steel the Mo_2C formation leads to a granular eutectoid with a stable M_6C carbide component. (*b*) In contrast to W_2C the carbide Mo_2C is formed directly during the isothermal decomposition of the austenite, and this was explained by the relatively higher stability of Mo_2C compared with that of the tungsten carbide. Thermodynamically the formation of Mo_2C appears to be favoured compared with that of either M_6C or $M_{23}C_6$. (*c*) The decomposition of martensite in the steel containing 0·38% C and 3·8% Mo is associated with the formation of the carbide Mo_2C; cementite was discovered only after a one-hour isothermal anneal. In the steels with still higher Mo contents the formation of cementite was altogether suppressed. (*d*) Cementite is one of the stable phases of the steels containing 0·35 and 0·45% Mo, and possibly also 2·1% Mo. However, the cementite formed as the result of the decomposition of the martensite in these steels disappears temporarily after annealing for about 100 h. Further 5000 h of annealing does not suffice to induce its reappearance. In the decomposition of austenite in the 0·35% C and 2·10% Mo steel, cementite formation was not observed, although cementite and MoC are equilibrium phases of this steel. The heat-treatment period of 5000 h was too short for the establishment of equilibrium. (*e*) The existence of a metastable carbide M_6C_b was established, and it was found that its formation is favoured by isothermal heating at comparatively low temperatures. (*f*) An explanation of the reaction kinetics involved in the formation of metastable carbide phases of the type observed requires a knowledge of the relative stabilities of these phases in the solid solution from which they are precipitated.—P. F.

Investigation of Carbide Phases of Tempered Carbon Steel. N. V. Gudkova, E. I. Levina, and V. A. Tolomasov. (*Fiz, Met. i Metalloved.*, 1957, **4**, (3), 500–504). There are two intermediate carbide phases in tempered carbon steel: low-temperature hexagonal with a Curie temperature of 380° C and high-temperature rhombic with a Curie temperature of 270° C and cementite. Chemical composition of the intermediate carbide phases differs from cementite. As the degree of dispersion of the carbide phases increases, the order of phase change is cementite, rhombic, hexagonal.—R. S.

On the Intermediate Transformation of Austenite. L. M. Pevzner, T. D. Kubyshkina, G. M. Rovenskii and A. I. Samoilov. (*Metall. Obra. Met.*, 1956, (10), 2–20). The intermediate transformation can be observed not only in the alloy elements forming the carbides but also in Si, Ni and Al steels and even in non-alloy steels. The difference between this intermediate transformation and pearlite is to be found in the change of the mechanism $\gamma \rightarrow \alpha$, i.e. in the transition through the kinetics of martensite with formation of particles coherently joined to the original lattice.—L. H.

On the Isothermal Decomposition of Austenite in Heat-Resisting Steels. R. P. Zaletaeva. (*Metallov. Obra. Met.*, 1955, (2), 25–28). The austenite in high-alloy steels brings its own complications to the chemical composition of the solid solutions. Its stability in austenitic is greater than in pearlitic and martensitic steels. The kinetics of isothermal disintegration of austenite in the Cr–Ni–Mo steel EI 395 (0·10% C; 0·6% Si; 1·3% Mn; 16·4% Cr; 24·9% Ni; 5·8% Mo; 0·018% P and 0·024% S) are investigated.—L. H.

Dilatometric Determination of Retained Austenite. Z. Csepiga. (*Koh. Lapok*, 1957, **12**, Apr.-May, 156–162). A mathematical method is given for calculating the retained austenite from random points on the dilatometric curve.—P. K.

Stabilisation of Residual Austenite of High-Speed and High Chromium Steels Against Tempering. Yu. A. Geller and R. P. Leshchinskaya. (*Metallov. Obra. Met.*, 1955, (1), 26–33). Stabilization against tempering develops by keeping the steels for 3–6 h at workshop temperature. It develops further for 24 h, but does not increase thereafter. An increase in Cr content in austenitic steels (high chromium) also promotes stabilization. Stabilization in high-speed steels at ~ 560° can be observed after one tempering. Due to the austenitic structure, the second tempering does not produce complete transformation, which is attained in many cases by a third tempering.—L. H.

The Mechanism of Austenite Transformation in Iron–Carbon Alloy. A. N. Alfimov. (*Metall. Obra. Met.*, 1956, (11), 23–25). The shear deformation of austenite in an iron–carbon alloy, as cause of the transformation, can explain the mechanism and kinetics of the formation of martensite, which is the primary product of the transformation, not depending on the stages of cooling. The formation of bainite and pearlite are secondary processes taking place at higher temperatures.—L. H.

The Bainitic Reaction. (Part I. Properties of the Bainitic Reaction). J. Čadek and D. Tlustá. (*Hutn. Listy*, 1958, **13**, (2), 123–133). [In Czech]. The characteristic features of the kinetics of the bainite reaction are discussed in the light of the literature on the subject. The reaction is compared with the ferrite and pearlite reactions on the one hand, and with the martensite reaction on the other. A far-reaching analogy between the martensite and bainite reactions is found although only the former is a diffusion controlled reaction. Concentration changes in the austenite occurring during the bainite reaction and the phenomenon of stabilization are considered in detail, and their probable significance is discussed. Measuring the lattice constant of the untransformed austenite is recommended as a means for elucidating the mechanisms involved.

Dimensional Changes of Hardened Ball Bearing Steel. Z. Csepiga. (*Koh. Lapok*, 1957, **12**, June, 228–234; Oct. 465–469). The degree of transformation of α-martensite and retained austenite in hardened ball-bearing steel causes dimensional changes. The amount transformed depends upon rate of heating, tempering temperature and time, and tempering cycle.—P. K.

The Time of Formation of Martensite Crystals. V. N. Arskii. (*Metall. Obra. Met.*, 1956, (11), 26–29). The experiments have established, among other facts, that the average rate of growth of the martensite crystal, determined as a relation between the diameter of the crystal and the time of its growth, is 10^6 mm/sec. This average rate does not depend on temperature, the activation energy of the process is therefore zero. The time of

crystal formation depends on its dimensions and averages 10^{-7} sec.—L. H.

Thermodynamics of Martensite Transformations. M. Hillert. (*Acta Met.*, 1958, **6**, Feb., 122–124). The causes of discrepancies between calculated values for the heat of transformation are analysed and it is shown that considering the transformation as adiabatic introduces uncertainties.—A. D. H.

The Martensite Transformation in Steel Kh 18. B. P. Gusynin. (*Metall. Obra. Met.*, 1956, (1), 26–29). This investigation has established the influence of temperature hardening and the states of the austenite at the initial and final temperatures of the martensite transformation in this steel. The complete martensite transformation depends on the rate of cooling over the martensite range and the transformation is speeded up with an increase in the rate of cooling.—L. H.

An Analysis of Phases Present in Resistance-Welded Joints of Plain and Low-Alloy Carbon Steels. I. Hrivňák. (*Hutn. Listy*, 1958, **13**, (3), 233–241). [In Czech]. A detailed study was made of the phases and their structure, primarily by electron microscopy. Evidence of the processes of decarburization, and of the diffusion of carbon into austenite and along the gamma iron grain boundaries was obtained.

Investigations of the Construction of the System Iron–Chromium–Carbon. K. Bungardt, E. Kunze and E. Horn. (**Arch. Eisenhüt.*, 1958, **29**, Mar., 193–205; Apr., 261). An account is given of the investigation of the ternary system Fe–Cr–C for up to 4% C and up to 38% Cr, using metallographic, dilatometric, X-ray and chemical techniques. An explanation of the symbols used is given in Part II.

CORROSION

New Tools Aid Corrosion Research. (*Steel*, 1958, **142**, June 23, 98). The purpose and equipment of the new Carpenter Steel Company's Corrosion Laboratory at Reading, Pa., are briefly described.—A. G.

Theory of the Corrosion of Metals and Methods of Developing Corrosion-Resistant Alloys. N. D. Tomashov. (*Problemy Korrozii i Zashchity Metallov. Proc. of the All-Union Conference on the Corrosion and Protection of Metals. U.S.S.R. Academy of Sciences, Inst. Phys. Chem., Moscow*, 1956, pp. 17–45). [In Russian]. After discussing the basic theory of the corrosion of metals, some factors are discussed which control corrosion, the corrosion properties of pure metals, the effect of structural heterogeneity on the corrosion-resistance of alloys, conditions associated with passivation and the increase of corrosion-resistance by the addition of cathodic elements (Pt, Pd and Cu). The following three fundamental possibilities associated with an increase in corrosion-resistance are compared: (*a*) creation of alloys which form a more complete surface protective layer consisting of the products of corrosion; (*b*) reduction of cathodic activity of the alloy; (*c*) reduction of anodic activity of the alloy. **Electrode Processes During the Corrosion of Metals in Oxidising Media.** V. P. Batrakov. (46–67). Oxidic and adsorbed films on the metal surface create a supplementary " barrier " and exert an enormous influence on the kinetics of the electrode processes. An examination of these processes which occur in oxidising media show that there are two fundamental possibilities: (*a*) the formation at the metal surface of protective films which retard the electrode processes; (*b*) the non-formation of such films. Conditions are discussed of anodic and cathodic polarization in both cases. The mechanism of self-passivation in oxidizing media and the conditions under which the metal passes from the active to the passive state and *vice versa* are studied. Conditions of repassivation are also examined. **Increasing the Stability of the Passive State of Stainless Steels.** N. D. Tomashov and G. P. Chernova. (68–78). The possibility is illustrated of increasing the corrosion-resistance of stainless steels by the introduction of certain metals which are effective micro-cathodes. Corrosion tests on 25% Cr steels to which various amounts of Pt, Pd, and Cu had been added showed that those steels which contained the cathodic additions exhibited a marked increase in their resistance to corrosion in sulphuric, formic and oxalic acids. Similar results were obtained on Cr–Ni steels exposed to sulphuric acid. **Influence of Additions on the Corrosion of Metals in Acid Media.** L. I. Antropov. (79–85). Conditions are discussed associated with the development of electrochemical corrosion. The action of inhibitors was studied in connection with electrostatic and specific adsorption. A combination of cathodic protection with molecular inhibitors is most effective when cathodic polarization causes the fixed potential to approach the zero point of the metal. **Effect of pH Value on the Corrosion Resistance and the Fixed Potentials of Metals.** A. Ya. Shatalov. (86–95). The corrosion and electrochemical behaviour of Ag, Cu, Mg, Zn, Cd, Al, Sn, Pb, Bi, Ti, Ta, Mo, W, Mn, Fe and Pt are studied in relation to a wide range of pH buffer solutions with varying concentration of Cl ions and in simple non-buffer mixtures containing a constant total concentration of anions. The minimum points are determined in the pH-corrosion curves for Cu, Zn, Al, Sn, Pb and Bi. The part played by diffusion factors throughout a wide range of pH values is assessed. Three separate cases of the influence of Cl ions on the pH-corrosion curves are established. **Investigation of the Corrosion of Iron in Halogen Hydracid Vapours, Using Tagged Atoms.** Z. A. Iofa and L. D. Shibaeva. (96–106). The acids used were : HI, HBr and HCl. It is shown that iron is corroded most rapidly in HI and most slowly in HBr. A study of the action of some volatile organic compounds on the rate of corrosion of iron in halogen hydracid vapours showed that the amines and aldehydes are the most powerful inhibitors in HI and HBr vapours but have only a weak effect in HCl vapours. The method of using isotopes was as follows: the HI contained ^{131}I. KI mixed with the iodine salt containing the ^{131}I was added to the sulphuric acid. In addition to determining the weight of the corrosion specimen, its radioactivity was also measured. **The Part Played by Colloid Chemical Phenomena in the Corrosion of Metals in Salt Solutions.** L. K. Lepin'. (107–114). The basic results of work undertaken in the colloid chemical field in relation to a study of the processes of corrosion in salt solutions with total immersion at room temperature are associated with the following factors in the kinetics of corrosion which explain the effect on the rate of corrosion: (*a*) the composition of the electrolyte (part played by cations and anions); (*b*) the concentration of the electrolyte; (*c*) the pH of the medium, and (*d*) the composition of the gaseous phase. In view of the part played by electrokinetic properties of the undissolved products of oxidation, it may be thought that these properties must also be important in the protection of metals by artificially applied non-metallic coatings. These coatings can be classified according to the intensity of these electro-kinetic properties and this provides a basis of developing more effective methods of improving the protective action of such coatings. **Sea-Water and Marine Atmospheric Corrosion of Steel.** V. F. Negreev. (115–125). This type of corrosion can be classified into four separate types: (1) corrosion in a marine atmosphere; (2) corrosion by periodic wetting with sea water; (3) corrosion by full immersion in sea water; (4) corrosion on the sea bottom. The following three types of protection are discussed: (*a*) cathodic protection with constant current; (*b*) periodic action; (*c*) use of a gradually decreasing current. **The Oxidised Surface of Steel as a Cathode.** A. F. Afanas'ev and E. N. Chankova. (126–135). The cathodic behaviour in aqueous alkaline solutions of low alloy steels coated with oxide layers of varying composition and that of the same steel free from oxides is studied. Those sections of the polarization curves produced with constant and with varying current density within which the potential determining processes were the electro-regeneration of oxygen, iron oxide and water, were determined. Some kinetic properties of these processes were established. It is shown that with an abundance of oxygen, the electrode potential is determined mainly by the processes of electro-regeneration of oxygen and water. The effect on electrode potential of the electro-regeneration of iron oxide is observed only when the supply of oxygen is small. **Beryllium Hydroxide—an Inhibitor in the Corrosion of Iron.** N. N. Balashova and N. D. Tomashov. (136–141). The possibility of using $BeCl_2$ as an inhibitor in the corrosion of iron in distilled water and in 3% NaCl solution is discussed. It is shown that, depending on the corrosive media, $BeCl_2$ can be both na anodic and a cathodic inhibitor, forming a hydroxide with a variable charge which is determined by the adsorption of the corresponding ions. **Effect of Temperature on the Corrosion of Stainless Steels in Hydrochloric and Nitric Acids and Mixtures.** A. I. Glukhova and G. V. Akimov. (142–149). It was established that the rate of corrosion of the austenitic stainless steels studied undergoes a particularly sharp increase in 0·1 N HCl at temperatures over 60° C. This effect is most disastrous in 18/8 Ti-stabilized steel and is least in 18/8 steel to which Mo has been added. 10% HNO_3, these steels completely resist corrosion up to 80° C. 2Kh18N9 grade is an exception because of intergranular corrosion. In mixtures of these acids, there is an increase in the rate of corrosion above 80° C, the above-mentioned steel in the tempered condition undergoing the maximum corrosion. Additions of both Ti and Mo reduce the effect of temperature in acid mixtures. **Influence of Surface Treatment of Stainless Steel on its Chemical Stability.** V. V. Andreeva and A. I. Glukhova. (150–159). Investigations showed that the method of surface treatment exerts a marked influence on the corrosion behaviour of stainless steels in various acid solutions. The effect of mechanical treatment depends largely on the properties of the solutions. Under conditions of corrosive media and temperature where a given steel is stable, the rate of corrosion is determined by the active surface area of the steel. The corrosion resistance of steel is reduced as the surface treatment becomes coarser, e.g. with polishing, grinding, machining, etc. In very aggressive media, on the other hand, the finer the surface treatment applied, the more pronounced is the rate of corrosion of stainless steel. **Theory of Cathodic Protection of Underground Installations.** A. F. Lunev. (160–172). The current required for the protection of underground installations is defined by a steep slope of the cathodic polarization curve of the protected material. In absolute value, the protective current exceeds the corrosion current and only in an exceptional case is it equal to it. The minimum protective potential is determined by the value of the potential of the initially anodic portions of the installations protected. The value of the protective potential is not constant but depends on the nature of the ground, the composition of the steel and other factors. In soils containing 20 to 5% moisture, the polarizing capacity of the steel electrode is increased compared with medium (10%) moist soils. An increase in the saltiness of the soil increases the cathodic polarizing capacity of the steel electrode and exerts a slight influence on the rate of the anodic process. The slope and nature of the cathodic polarization curve depend largely on the rate at which oxygen arrives at the metal surface and the amount of oxygen. In neutral soils, the amount of electricity passing through the cathode corresponds strictly to the amount of ionized oxygen. **Complex Electro-Protection Against Corrosion of the Dashava to Kiev Gas Pipeline.** I. N. Frantsevich, V. S. Chernovol, I. S. Gerenrot, N. A. Pilipenko and L. N. Yagupol'skaya. (173–189). A combination of high grade insulation and complex electro-protection of a gas pipeline immediately after completion of pipe-laying is the only effective and economical method of protection against corrosive soils and stray currents. A check on the efficiency of the electro-protective medium must be carried out by measuring the pipe-to-soil potentials. The permissible variation in

potential for pipe-lines with indestructible insulation is 0·85 to 1·30 referred to a copper sulphate electrode. As the condition of the insulation deteriorates, the top limit of potential must be lowered and intermediate means of electro-protection must be used. For the protection of underground pipe-lines with branch communications which are subject to soil corrosion and stray currents, the only effective method is complex drainage-cathodic protection. **Kinetics of Electrode Processes in the Soil Corrosion of Metals.** N. D. Tomashov and Yu. N. Mikhailovskii. (190–208). It is shown that, when cathodic polarization of an iron electrode in soil (moist sand) occurs, with a constant current density in a closed space, the variation in cathode potential with time is determined by a reduction in the concentration of oxygen in the soil. The mechanism of oxygen recovery at the iron cathode in moist soil is similar to the mechanism of ionization of oxygen in electrolytes. The mechanism of the molecular transfer of oxygen to the cathode in moist soil is discussed. An increase in the moisture content or in the amount of colloidal fraction in sandy soil reduces the coefficient of oxygen permeability of the soil as a result of the filling up of the pores and capillaries with liquid and highly dispersed particles which causes a reduction of the total diffusion current of oxygen. The authors investigate the relationship between the limiting diffusion current of oxygen during the cathodic polarization of an iron electrode in soil and the moisture content of sand and clay. The determination of the densities of the limiting diffusion currents of oxygen in various soils enables us to evaluate the corrosivity of the soil in relation to the ease of penetration of the cathodic process which occurs in the soil corrosion of metals. **Investigation of the Behaviour of Protective Films on Aluminium in Various Solutions by Measuring the Resistance and Capacitance.** G. V. Akimov, G. B. Klark and N. I. Isaev. (209–226). **Corrosion and Electrolytically Polished Aluminium.** P. V. Shichigolev. (227–236).

Chemical and Electrochemical Affinities of Corrosion Processes. P. Van Rysselberghe. (*Corros. Techn.*, 1958, **5**, Feb., 49–52, 62). The author presents an analysis of corrosion reactions based on the concepts of chemical and electrochemical affinities, the principles of equilibrium thermodynamics and the thermodynamics of irreversible processes. The corrosion of metallic zinc in aqueous media is taken as a typical example. (13 references).

Review of Factors Which Influence the Corrosion of Iron and Steel. R. Mamuzic. (*Zastita Mat.*, 1956, **4**, Oct., 330–332). Factors which accelerate corrosion processes are reviewed. Each has its effect when acting alone but combinations of several factors render the processes complicated so that the effects cannot be disentangled. Complex systems have more relevance to practical conditions than the simplified conditions of the laboratory.

Galvanic Corrosion. N. Gašparevic. (*Zastita Mat.*, 1956, **4**, Oct., 328–329, 336). A review.

Mechanism of the Corrosion of Steel in Gases. N. P. Zhuk. (*Zhur. Fiz. Khim.*, 1956, **30**, May, 1173–1177). The mechanism of the corrosion of steel in gases is discussed, with reference to specimens of mild steel (C 0·15%, Mn 0·35%, Si 0·20%) in pure H_2S at various temperatures.

Mechanism of the Corrosion of Metals in Fused Chlorides. N. D. Tomashov and N. I. Tugarinov. (*Zhur. Priklad. Khim.*, 1957, **30**, (11), 1619–1625). In the investigation described the corrosion mechanism of iron in fused chlorides was studied with the application of modern theoretical and practical methods developed for aqueous solutions of electrolytes. With Armco iron the activity increased from NaCl to KCl to $CaCl_2$, about 70% of the surface corrosion being concentrated near the crystal boundaries. Activation energies for different values of the iron electrode potential are calculated from polarization curves and used to discuss the corrosion mechanism. Passage of air, O_2, CO_2 and water vapour through the melt raised the density of the limit cathodic diffusion current; sulphate, carbonate, nitrate and nitrite ions acting as cathodic depolarizers. The corrosion was proved to be electrochemical in character. Anti-corrosion measures are recommended.

Corrosion Activity of the Nitrate–Nitrite Corrosion Mixture. E. I. Gurovich and G. P. Shtokman. (*Zhur. Priklad. Khim.*, 1957, **30**, (10), 1547–1552). [In Russian]. The mixture contains 53% by weight KNO_3, 40% of $NaNO_3$ and 7% of $NaNO_2$. It has been given the name of Nitrate–Nitrite corrosion mixture. Various types of steels have been subjected to the action of this mixture. Some were found resistant and others not. Nickel, of all metals tried, has shown itself the most resistant to the action of the fused mixture of these salts.

Corrosion of Metals by Hydrogen Sulphide at Elevated Temperatures. Kh. L. Tseitlin, L. V. Merzloukhova and V. A. Strunkin. (*Zhur. Priklad. Khim.*, 1957, **30**, (10), 1553–1557). [In Russian]. Dry H_2S above 250° causes considerable corrosion in iron and steel especially at ~ 500°. One type of stainless steel tested shows an increase in corrosion at 360°. Up to 500°, Al and a type of Cr–Al steel show good resistance. Of all metals, Cu shows the greatest tendency to corrosion by H_2S, starting as low as 170°.—L. H.

The Electrochemical Series of Metals in Practical Corrosive Media. J. Elze and G. Oelsner. (*Metalloberfläche*, 1958, **12**, May, 129–133). An electrochemical series of metals was obtained, in reference to the standard hydrogen electrode, for a large number of metals and alloys. Some carbon and alloy steels are included, together with a hard chromium coating on steel, for two corrosive media.—L. D. H.

Elchemographic Measurements in Corrosion Research. V. Cupr. (*Werks. Korr.*, 1958, **9**, Feb., 76–82). The method gives a continuous photographic record of potentials and currents under any desired condition of polarization using interrupted currents. This gives the value for potential in the absence of current and shows up transient effects as well as the values usually measured with polarized electrodes. The method is extended to capacitative systems and the effects of capacity on current and potential are obtained and applied to the theory of local cells. These cases are formulated with equivalent circuits.

The Structural Engineer in Corrosion Protection. J. Baudin. (*Corros. et Anticorros.*, 1957, **5**, Oct., 269–274). The author discusses the functions of a corrosion department and its relation to other departments within the organisation. He stresses the economic considerations of corrosion and gives a summary of methods for corrosion prevention and control.—R. P.

Inter Society Corrosion Committee Glossary of Corrosion Terms. *I.S.C.C.* Sub-Committee on Standard Definitions and Terminology (A. de S. Brasunas, Chairman). (*Corrosion*, 1958, **14**, Feb., 71–72). Definitions of 53 commonly used corrosion terms are given.—J. F. S.

On the Composition of Rust on Iron in Contact with Water and Air. I. V. Krotov. (*Zhur. Fiz. Khim.*, 1956, **30**, (8), 1696–1701). The presence of a maximum (at 676°) and of two minima, (at 149° and 247°) in the differential curve given by plotting temperature of rusted powdered iron in air, moistened with distilled water, justify the conclusion that preformed rust consists apparently of γ-FeOOH which up to 149° loses absorbed moisture. During a further increase in temperature it is likely that γ-FeOOH is transformed into γ-Fe_2O_3. This process is completed at a temperature approximating 290°. At temperatures near 676° the process of transformation from γ-Fe_2O_3 to α-Fe_2O_3 is completed.—L. H.

The Causes of the Formation of a Thin Film of Rust in Cast Iron. G. Schikorr. (*Metalloberfläche*, 1958, **12**, Mar., 81–84). Drops of water, distilled or containing chloride or sulphate, were allowed to form spots of rust on a flat sample of cast iron. After grinding off a thin layer, and exposing the new surface to a moist atmosphere, subsequently re-grinding and repeating the exposure several times, it was shown that water containing chloride produced spots which persisted in re-rusting until 200–300μ had been ground off. The conclusion drawn was that chloride irons penetrate the iron surface by way of the graphite lamellæ to an appreciable depth.

Corrosion of Metals and Other Materials in Very Aggressive Industrial Atmospheres. Z. Milan. (*Zastita Mat.*, 1957, **5**, July, 254–257). Impurities causing corrosion present in rural, urban, industrial, coastal and special atmospheres are reviewed, and their effects on metals considered. Observations at Zenica are particularly considered.

A Review of Low Temperature Corrosion from the Combustion Gases in Oil Burning Plant. G. F. J. Murray. (*Schweiz. Arch. Wiss. Techn.*, 1957, **23**, Sept., 280–292). The author discusses oil fuel characteristics with special reference to conditions leading to SO_3-formation. Experiments to lower the acid dew-point of the flue gases by adding alkali to the fuel-oil; the combustion space or flue gas stream are described. The BP Corrosion Control Process, using ammonia, is described in detail.—R. P.

Variables Influencing Corrosivity of Oil and Gas Welds. H. E. Waldrip and J. A. Rowe. (*Corrosion*, 1958, **14**, Feb., *Technical Topics*, 108–120). The influence of the wettability of a crude oil on the corrosivity of well fluids is described with particular reference to the function of inhibitors. A method of evaluating inhibitors by drop-size ratio measurements is reported with a note of anomalies and the effect of sulphides. The many types of inhibitor used are compared. The difficulty of relating oil well corrosion to well variables is considered in respect of temperature, pressure, CO_2 content, organic acid content and velocity. The influences of inhomogeneities in the steel and of human error are considered. Among the unsolved problems are reasons for pitting, mechanics of corrosion, function of inhibitors and the correlation of data on well treatment.

The Fight Against Corrosion in the Petroleum Industry. J. Tourret. (*Mét. Constr. Mécan.*, 1958, **90**, Apr., 285–289). The author describes the corrosion problems peculiar to the petroleum industry which are faced by the engineer on the plant. Methods of control are outlined.

The Periodic Solution of Iron into the Soil. Corrosion of Iron in the Presence of Hydrochloric Acid in the Atmosphere. P. Kirkov. (*Werks. Korr.*, 1958, **9**, Mar., 146–149). The solution of iron in quartz sand with 86% of SiO_2 was investigated, with a particle size between 0·1 and 1·4 mm, in air at 20° C in the presence of strong mineral acid, ($1 \cdot 10^{-3}$ to $1 \cdot 10^{-1}$ N HCl). It was established that iron under these conditions goes into solution by a periodic process, that the period of solution sets in every 70 h and that this period, as regards the time, is not affected by a change of the concentration of acid in the soil.—L. H.

Corrosive Conditions in Mines. M. Kobliška. (*Zastita Mat.*, 1957, **5**, Feb., 62–65). A review of the conditions of temperature, humidity and the presence of solutions of salts and gases which cause corrosion. Plants for the concentration and treatment of ores have different conditions.

Corrosion of Steel Wire Ropes and Its Prevention. F. Podbrežnik. (*Zastita Mat.*, 1957, **5**, Feb., 58–62). Phosphate treatment is mentioned particularly. Corrosion in contact with other materials is reviewed.

The Surfaces of Metallic Substances in Relation to their Influence on the Behaviour in Use of Structural Parts. H. Wiegand. (*Metalloberfläche*, 1958, **12**, Feb., 33–37; Mar., 65–68). The influence of physical and corrosive action on metallic surfaces is discussed. Protective layers and their effect in the behaviour of the metal in use are then considered.—L. D. H.

Stress Corrosion. S. Berg. (*Tekn. Ukeblad*, 1958, **105**, Apr. 10, 323–331). A review is given of theories of the mechanism of stress corrosion, followed by a description of investigations carried out with a new apparatus, in which resistance to stress corrosion in calcium and magnesium chloride was compared at various pH values.

Stress-Corrosion Cracking of Austenitic Stainless Steels in Aqueous Chloride Solution. T. P. Hoar and J. G. Hines. (*Zastita Mat.*, 1957, **5**, Apr., 127–134, 137). Presented at a conference in Zagreb May-June, 1956. An English translation is given. Experiments on wire specimens are reported and the qualitative mechanism of cracking, crack initiation and propagation is discussed.

Influence of Surface Layers on the Stress Corrosion of Steel. H. Gräfen. (*Arch. Eisenhütt.*, 1958, **29**, Apr., 225–229). Equipment and experiments are described in which, by means of long-term corrosion tests, the influence of the formation of surface films on the incidence of stress corrosion cracking is investigated. Intercrystalline stress corrosion cracking of plain carbon and alloy steels was examined in nitrate and halide solutions, and the influence of oxygen in the corrosive agent was studied. Transcrystalline corrosion cracking in austenitic steels was investigated in chloride solutions, with and without oxygen additions.

Caustic Cracking of Mild Steel for Boilers. N. Collari and P. Virdis. (*Calore*, 1958, **29**, Feb., 47–57). This is a description of the cause and nature of the caustic cracking of boilerplate, followed by a review of the various theories advanced to explain its occurrence. (26 references).

Effect of Low-Temperature Stress-Relief on Stress Corrosion Cracking. C. R. McKinsey. (*Rev. Soudure*, 1958, **14**, (1), 42–49). A series of experiments was carried out on butt-welded sheet steel samples to determine the effect of a low-temperature stress-relieving treatment on the incidence of stress corrosion cracking. It was found (1) that the susceptibility to cracking increased with decreasing carbon content, both in killed and rimming steels (2) the stress-relieving treatment reduced greatly the tendency to cracking.

Types of Corrosion Met with when Using 18/8 Stainless Steel Tubes. J. Dedieu and L. Pennec. (*Corros. et Anticorros.*, 1957, **5**, Nov., 348–358). The authors review the types of corrosion which can occur in 18/8 stainless steel, discussing causes and possible remedies or prevention. Intergranular corrosion of stabilized 18/8 steel can be prevented by stress-relief annealing at 900° C; water quenching is to be avoided.—R. P.

Underground Corrosion—Part 2: Behaviour of Protective Coatings in Soils. M. Romanoff. (*Corros. Techn.*, 1958, **5**, Feb., 45–48, 56). This second article is a summary of that section in a report by the U.S. National Bureau of Standards which deals with the study of the protection of pipes by various metallic coatings, bituminous coatings and by the incorporation of alloying metals into the pipe metal itself. The ASTM weather exposure tests on galvanized steel showed that the relative protection was a function of the total amount of zinc and not of the method of application. In the case of lead-coated steels, large areas of the coating corroded away in many of the soils, particularly in cinders and in poorly drained soils. Tin coatings on copper were found to be appreciably susceptible to corrosive attack, especially so in cinders and in poorly aerated organic soils. The article concludes with a discussion of the relative merits of asphalt-base and coal tar-base bituminous coatings, the precautions to be observed and the methods of detecting pinholes and flaws.—L. E. W.

Electrode Potential Studies on Iron in Dilute Phosphate–Chromate Solutions. R. N. Ride. (*J. App. Chem.*, 1958, **8**, Mar., 175–183). The potential is reproducible in aerated KH_2PO_4 at pH 5·2 and 6·1, addition of $K_2Cr_2O_7$ raises the potential logarithmically and a new passive layer forms. When chromate is present from the start behaviour is unpredictable.

Electrochemical Methods of Investigating Atmospheric Corrosion in an Air Humidity of 100% and Lower. Yu. N. Mikhailovskii and N. D. Tomashov. (*Zavods. Lab.*, 1957, (12), 1462–1466). [In Russian]. A new method of investigation is described in which the electrodes consist of 20–50 μ foils of 100 mm length of the metals under investigation. Graphs showing the anode and cathode polarization of metals in a 100% humid atmosphere; the anode polarization of zinc and iron and the cathode polarization of copper, and the relation of the anode polarization of metals as a function of atmospheric humidity, are given.

Method for Corrosion Testing. W. Wiederholt. (*Werks. Korr.*, 1958, **9**, Mar., 133–146). The object of corrosion tests in the laboratory is not to destroy the specimen because anti-corrosion measures afford only temporary protection. The object is rather to determine the safe period afforded by the protection. Tests are described, by simulating climatic conditions, concerning temperature, moisture and concentrations of various gases in the atmosphere.—L. H.

Test Conditions for the Study of Corrosion Cracking in H_2S. E. Herzog. (*Rev. Mét.*, 1958, **55**, Feb., 123–144). Tests have been carried out on mild and low-alloy steels under stress in aqueous H_2S solutions. The influence of heat treatment on the resistance to stress-corrosion cracking is discussed in detail.—B. G. B.

Kinetics of Reaction of Steel with Hydrogen Sulphide–Hydrogen Mixtures. A. Dravnieks and C. H. Samans. (*J. Electrochem. Soc.*, 1958, **105**, Apr., 183–191). The rate decreases as the equilibrium $Fe + H_2S = FeS + H_2$ is approached. The process was studied up to 540° C and at pressures up to 20 atm which increase the reaction rate. The same consecutive linear and parabolic rates noted in pure H_2S occur but traces of O_2 reduce the linear component. The observed kinetics are resolved into three steps corresponding to adsorption, rate of formation of diffusing species and diffusion. The mechanism of sulphidization is discussed.

Corrosion Products of Mild Steel in Hydrogen Sulphide Environments. F. H. Meyer, O. L. Riggs, R. L. McGlasson and J. D. Sudbury. (*Corrosion*, 1958, **14**, Feb., 109–115). An X-ray diffraction technique has been developed which has led to the identification of the first iron sulphide solid structure which forms when mild steel is corroded at room temperature by H_2S gas passed through water or brine. This primary corrosion product is described as kansite (Fe_9S_8). A proposed mechanism of the corrosion processes in moist H_2S and the effects of impurities are discussed. Kansite tarnish formed initially changes to kansite scale with a higher corrosion rate which is only reduced when conditions favour the formation of outer layers of pyrrhotite and pyrites scales.—J. F. S.

Electrochemical Deterioration of Graphite and High-Silicon Iron Anodes in Sodium Chloride Electrolytes. S. Tudor, W. L. Miller, A. Ticker and H. S. Preiser. (*Corrosion*, 1958, **14**, Feb., 93–99). Graphite and silicon–iron anodes for impressed-current cathodic protection systems were subjected to laboratory tests to determine their electrochemical deterioration in NaCl solutions. The effects of specific resistivity of the electrolyte and of current density were studied. In high-resistivity solutions less deterioration occurred on the silicon–iron than on the graphite. In low-resistivity solutions chemical attack on silicon–iron by chlorine generated and trapped at the anode can be considerable.—J. F. S.

Metals and Alloys Resistant to Acids at High Temperatures. M. Pajevic. (*Zastita Mat.*, 1957, **5**, July, 243–247). The effects of passivating coatings on metals and the importance of alloying elements in steel are reviewed. Resistance to SO_3, CO_2 and H_2 is discussed. Coating processes are outlined and the resistance of steels to boiling H_2SO_4 and acetic acid is tabulated.

Dissolution of Metals in Aqueous Acid Solutions. II. Depolarized Dissolution of Mild Steel. A. C. Makrides and N. Hackerman. (*J. Electrochem. Soc.*, 1958, **105**, Mar., 156–162). Effects of stirring, depolarizer concentration and temperature indicate that the process is diffusion-controlled. Rate constant depends on stirring velocity by a power close to unity, suggesting that this depends upon the effect of surface irregularities on flow conditions. When these irregularities are of a height comparable with the thickness of the laminar sublayer the effective surface area may be larger than the projected geometric area. $FeCl_3$, benzoquinone and *p*-toluquinone were used in 2 N–HCl.

Investigation on Acid-Resistant High-Silicon Iron. III. Effects of Cooling Rate and Annealing on Mechanical Properties and Corrosion Resistance. H. Sawamura, O. Tajima and K. Akamatsu. (*Tetsu-to-Hagane*, 1958, **44**, Feb., 111–115). [In Japanese]. Variations in cooling rate produce great changes in graphite structure, and influence the mechanical properties but have negligible effect on the corrosion resistance. Annealing of castings is only important in respect of relief of internal casting stress.—K. E. J.

Corrosion of Stainless Steels in Boiling Acids and its Suppression by Ferric Salts. M. A. Streicher. (*Corrosion*, 1958, **14**, Feb., 59–70). A detailed study is reported of the influence of the composition of stainless steels on their resistance to corrosion by eight acids. Environmental factors, including acid concentration, corrosion products and oxygen, were also investigated. The acids used were oxalic, formic, acetic, glycollic, phosphoric, sulphuric, sulphamic, and sodium bisulphate and the steels included straight chromium, 18/8 Cr–Ni and some Cr–Mn–Ni steels. Corrosion of stainless steels in these acids is inhibited sufficiently by the action of soluble ferric salts in amounts exceeding a certain critical concentration to retain the bright finish over long periods in boiling acids. The minimum amount of ferric ions for inhibition depends on the alloy content of the steel. The corrosion behaviour of a 17·6% Cr, 5·6% Mn, 4·4% Ni steel was found to be very similar to that of 19/8 Cr–Ni stainless steel.—J. F. S.

Materials for Sulphuric Acid. E. Rabald. (*Zastita Mat.*, 1956, **4**, June, 193–197). Steels and other alloys in contact with various concentrations of H_2SO_4 are reviewed. Plastics are included.

Corrosion of Steel by Hydrochloric Acid in the Spheroidal Condition. Kh. L. Tseitlin and S. M. Babitskaya. (*Zhur. Priklad. Khimii*, 1958, **31**, (1), 84–89). At a sufficiently high temperature hydrochloric acid decomposes into a mixture of steam and vapour, acting differently from the original acid. This article deals with the corrosion of steel by the acid in the spheroidal state i.e. when droplets separate out on the heated surface with an insulating layer of the mixed vapour $HCl–H_2O$. The special apparatus used together with the results of the experiments are detailed.—L. H.

Investigation of the Corrosion of Zinc, Iron, Aluminium and Magnesium in Water–Dioxane Solutions of Some Electrolytes. Yu. B. Kletenik. (*Zhur. Priklad. Khim.*, 1957, **30**, (11), 1626–1632). The corrosion of Zn, Fe and Al in water–dioxane solutions of sulphuric and hydrochloric acids and of Fe and Al in water–dioxane solutions of chlorides was studied. It was found that, in sulphuric acid solutions, passivation occurs which is most pronounced for zinc and is attributed to adsorption of a dioxane–sulphuric acid complex. Magnesium corrosion was also studied and the corrosion-rate curves for this and Al were found to differ sharply from those for iron and zinc. The influence of chloride ions and of dioxane on the corrosion of passivated metals is discussed.—S. K.

On the Problem of Investigating Steels Resistant to the Action of Low-Nitric–Sulphuric Acid Mixtures. E. V. Zotova and A. A. Babakov. (*Zhur. Priklad. Khim.*, 1957, **30**, (12), 1795–1799). [In Russian]. The acid mixture contains 76% H_2SO_4 and 0·05% HNO_3, Sp. Gr. 1·675. The investigation aimed at elucidating the influence of Cr, Ni and also carbon on the corrosion of Cr–Ni–Mo steels in low-nitric–sulphuric acid below 130° under industrial conditions of production at sulphuric acid plants. These have shown that the corrosion of low-carbon Cr–Ni–Mo steels, with a Cr content between 5–27% and Ni content between 9–28% but with a fixed content of 3% Cu and 3% Mo, depends, between 120–135°, mainly on the Cr content and less on that of Ni.—L. H.

Dependence of the Rate of Corrosion of Iron

on the pH of Solutions and the Passivation of Metals in Alkaline Solutions. L. K. Lenin', A. Ya. Vaivade, Z. F. Oshis. (*Zhur. Fiz. Kim.*, 1955, **29**, (2), 350–355). [In Russian]. The experiments covered the kinetics of the oxidation of iron in solutions of pure KOH and in solutions of KOH–KCl. The solutions were of different pH (9–14). The structural modification of the hydroxides from γ to α occurs at different pH values.—L. H.

Studies on Corrosion of 18 8 Stainless Steels for Uranyl Salt Solutions. T. Kurovanagi, N. Shinoda, R. Hasiguti and G. Ito. (*Tetsu-to-Hagane*, 1957, **43**, Dec., 1312–1317). [In Japanese]. Satisfactory steels for tanks and piping of a nuclear reactor using an aqueous solution are described. Parts in contact with the solution gave a better performance after previous immersion in the solution for 1–3 days and washing.—K. E. J.

Corrosion of Some Metals and Alloys in Uranium Hexafluoride. D. Heymann and F. E. T. Kelling. (*Corros. Techn.*, 1958, **5**, May, 148–151, 158). The authors present and discuss the results of investigations into the corrosion of Al, Cu and Ni, Cu alloys, Ti alloys and a number of steels by UF_6. The excellent properties of Ni, monel, Cu and Al were confirmed and Ti alloys were found to possess good resistance. The resistance of ordinary steels was highly satisfactory and that of stainless steels with high Ni content was excellent. There were indications that increasing carbon in ordinary steels decreased the resistance but the effect was not pronounced. The results suggested that Cr has an unfavourable and Ni a favourable influence.

Immersion Tests with Cast Iron and Steel Plate in Relation to Corrosion in Open Shafts. W. Sardemann. (*Glückauf*, 1958, **94**, 9/10, 338–345). Unprotected cast iron plates exposed to tap water and to brine for 6 years suffered less corrosion attack than steel plate. With waste water, the attack on iron and steel was almost the same. Protected plates were hardly corroded. The use of iron and steel sheet in shafts in relation to changes in mechanical properties are discussed.—R. P.

Contribution to the Determination of Changes in Thickness of Steel Sheet and Pipes Caused by Corrosion. M. G. Pirou. (*Corros. et Anticorros.*, 1957, **5**, Nov., 339–347). This paper reviews several non-destructive methods of determining changes in thickness of steel sheet and pipes. The magnetic method is recommended, the apparatus being inexpensive, robust and easily operated.—R. P.

Atmospheric Exposure Tests of Different Types of Electrodeposited Nickel. J. Edwards. (*Prod. Fin.*, 1958, **11**, March, 58–66). The corrosion protection given by dull, four kinds of organic bright, organic semi-bright and cobalt bright nickel electrodeposits on mild steel pressings in marine and industrial atmospheres was determined. No important differences in protectiveness or corrosion resistance were found.—A. D. H.

Inhibitors for Acids. J. Tomislav and S. Milanko. (*Zastita Mat.*, 1957, **5**, June, 201–203). Organic inhibitors for pickling in H_2SO_4 are reviewed. *o*-Tolylthiourea and phenylthiourea are especially recommended.

Comparative Experiments on the Corrosion-Inhibiting Effect of Organic Compounds in Aqueous Solution. W. Funke and K. Hamann. (*Werks. Korr.*, 1958, **9**, April, 202–216). Weight-analysis corrosion tests, and tests in non-acid, aqueous, aerated solutions have been carried out with a number of organic corrosion-inhibiting compounds.—L. J. L.

Vapour-Phase Corrosion Inhibitors. S. Rowden. (*Corros. Techn.*, 1958, **5**, April, 117–121, 126). The author describes the development of V.C.I. compounds since 1945 with particular reference to the principal classes of chemicals that have been investigated. Various volatile ammonium salts e.g. di*cyclo*hexyl ammonium nitrite, have been used successfully. Sodium benzoate has given variable results depending on the metal tested. The factors affecting V.C.I.s are discussed in some detail and it is concluded that volatile corrosion inhibitors of high potency may become valueless in a severe test. The need for more sophisticated test methods is stressed. (13 references).—L. E. W.

The Inhibiting Effect of Sodium Benzoate on the Atmospheric Corrosion of Mild Steel. O. Šarc-Lahodny. (*Zastita Mat.*, 1956, **4**, Oct., 324–327). As little as 1% aqueous solution afforded complete protection in alternate immersion tests. Suspensions in machine oil were more effective than the oil alone. Highly polished steel surfaces immersed in 1% solution and dried resisted solutions of the composition of perspiration. Wrapping in impregnated paper was also satisfactory.

Corrosion Inhibition by Organic Amines. H. Kaesche and N. Hackerman. (*J. Electrochem. Soc.*, 1958, **105**, Apr., 191–198). Corrosion of pure Fe in N HCl is discussed in terms of the theory of mixed potentials. Aniline and its *A*-alkyl derivatives and aliphatic primary amines were used and cathodic polarization measurements as well as analysis of the solutions were employed. All show maximum efficiency at $\sim 0{\cdot}1$ mole/l. Data on cathodic inhibition are interpreted but anodic inhibition is found difficult to explain without more satisfactory experimental values.

Experiences with Filming Amines in Finland. P. Kajanne. (*Corros. Prev.*, 1957, **4**, Dec., 49–53). The author points out that O_2 and CO_2 are the primary causes of corrosion in boilers and heat transmission equipment. Combined CO_2 is liberated only at boiler temperature and is usually neutralized by ammonia which leads to corrosion of copper alloy parts by the ammonia. The latest development in the prevention of such corrosion is to form a protective film of amine on the metallic surface. Film-forming amines also improve heat transfer by changing water condensation from films to drops. (16 references).—L. E. W.

Effect of Inhibitors in Fuming Nitric Acid on Corrosion and Oxidation. Tin Boo Yee. (*Corrosion*, 1958, **14**, Feb., 82–84). A method is described for testing the effectiveness of an inhibitor in suppressing the corrosion of stainless steel in fuming nitric acid and another for testing the oxidizing powers of the inhibited acid. I_2, I_2O_5, KI and KIO_3 were the best inhibitors investigated. The oxidizing power of the acid was increased by the addition of $0{\cdot}5\%$ I_2, I_2O_5 or KI but decreased by 1% of KI or $0{\cdot}5\%$ of KIO_3.

Nitrite Inhibition of Corrosion: Some Practical Cases. T. P. Hoar. (*Corrosion*, 1958, **14**, Feb., 103–104). Instances of the use in the United Kingdom of nitrites to inhibit the corrosion of metals are described. The possible mechanism of inhibition is compared with that for chromates.—J. F. S.

Progress in Rust Protection. H. Hebberling. (*Werks. Korr.*, 1958, **9**, Mar., 150–152). The German Federal Railways call for forge scale removal and recommend the use of passivating wash primers instead of oil films. It is thought that these measures may be obsolete as may also be the use of barytes and cheap red lead which was taken over from the practice of the old Imperial Railways.

The Economics of Material Protection. R. Jovanovic. (*Zastita Mat.*, 1957, **5**, June, 210–214; July, 258–260). Actual examples are given and the costs and value of protection are estimated.

Temporary Protection of Metallic Surfaces Against Atmospheric Corrosion. N. Plavšic. (*Zastita Mat.*, 1956, **4**, May, 159–164). A review.

Protection of Materials in a Polluted Industrial Atmosphere. Z. Milan. (*Zastita Mat.*, 1957, **5**, Aug., 296–299). Plating, especially with Al, is considered.

ANALYSIS

Gravimetric Determination of Iron with Benzenephosphinic Acid. J. E. Banks. (*Anal. Chim. Acta*, 1958, **19**, Oct., 331–333).

Experiences and Sources of Error in the Determination of Graphite in Grey Cast Iron with Filter Sleeves, As Proposed by Dr. Kraus. H. Auerbach. (*Giessereitechn.*, 1958, **4**, Mar., 60–61). Sources of error in the determination of graphite in grey cast iron by the technique proposed by Kraus (*ibid*, 1956, **3**, (6)) are discussed, and a modified procedure developed.

The Influence of Sampling on the Chemical Analysis of Grey Cast Iron. H. Auerbach. (*Giessereitechnik*, 1958, **4**, Feb., 35–37). Grey cast iron borings were screened into five fractions, each of which was analysed. It was concluded, by comparing the results with a sample analysed by a standard procedure, that sufficiently accurate results could be obtained, provided that the fraction of less than 0·1 mm was kept proportionally low.

The Principal Impurities in Pig Iron and their Chemical Determination. T.-K. Willmer. (*Arch. Eisenhüt.*, 1958, **29**, Mar., 159–164). Methods were investigated by the chemical committee of V.D.E. for the analysis of trace elements found in pig iron, i.e. elements contained in concentrations not less than $0{\cdot}001\%$ and not more than a few tenths%. Methods were selected as suitable on the grounds of convenience and cost, and included the determination of Al, Co, Cr, Cu, Mo, Ni, Ti, V, As, Sb, Sn and Pb. The accuracies and times of analysis of the selected methods are given. (19 references).

Colorimetric Determination of the Iron Carbide Content of Steels. N. M. Popova and L. V. Zaslavskaya. (*Zavods. Lab.*, 1958, **24**, (1), 26–29). It was found that finely divided iron carbide, when heated with sodium picrate, gives a reddish brown colour. Under controlled conditions the coloration is proportional to the concentration of carbide. Experiments were carried out on samples of Y8 steel, heat treated at different temperatures; the carbide was first separated by anodic solution. The results are discussed.—L. D. H.

Rapid Photometric Determination of Phosphorus in Steel. S. Wakamatsu. (*Tetsu-to-Hagane*, 1957, **43**, Dec., 1325–1329). [In Japanese]. The method described shows advantages over the conventional photometric method. (10 references).—K. E. J.

Colorimetric Determination of Manganese and Nickel. A. Serres. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, **4**, (10), 2081–2084). For Mn in steels containing high Cr contents the Mn is oxidized by KIO_4 and the amount of the MnO_4 ion determined photocolorimetrically. The determination of Ni in a number of different steels is discussed.—B. G. B.

Colorimetric Determination of Titanium in Alloy Steels by the Addition Method. A. I. Lazarev and V. I. Lazareva. (*Zavods. Lab.*, 1958, **24**, (2), 145–146). Three aliquots are taken from a sulphuric acid solution of the alloy oxidized with nitric acid. One is used as a blank, a small, known amount of Ti is added to the second, the Ti colour developed in the second and third portions with hydrogen peroxide, and their optical densities measured photometrically at 400 mμ. The Ti in the alloy is then calculated.—L. D. H.

Photometric Determination of Tungsten in Steel and Titanium Alloys with Dithiol. L. A. Machlan and J. L. Hague. (*J. Res. N.B.S.*, 1957, **59**, Dec., 415–420). Measurements are made at 635 mμ. Accuracy is $\pm 0{\cdot}005\%$ W or better in the range $0{\cdot}05$–$0{\cdot}5\%$ W and $\sim \pm 0{\cdot}001\%$ for quantities below $0{\cdot}05\%$ W.

Analytical Solvent Extraction of Vanadium Using Acetylacetone. [Pentane-2 : 4-dione]. J. P. McKaveney and H. Freiser. (*Anal. Chem.*, 1958, **30**, Aug. part 1, 526–539). The tervalent form is most easily extracted with equal volumes of $C_5H_8O_2$ and $CHCl_3$.

Photometric Determination of Iron in Pure Tin and in Tin Melts for Tinning Steel Sheet. H. Ploum. (*Arch. Eisenhüt.*, 1958, **29**, Mar., 169–172). Fe is determined photometrically in the presence of a large excess of Zn by means of the colour developed with ammonium thioglycolate. Absorption is measured at 530 mμ, the analysis is taking about 20 min. As, Sb, Bi, Cu, Pb and Mn up to $0{\cdot}88\%$ do not interfere; the interference of Cr and Ni at this order of concentration is negligible; Co should be absent.

Determination of Copper, Bismuth, Tin, Antimony, Arsenic and Lead in Ferrotungsten. H. M. Kostyanovskaya and M. V. Babaev. (*Zavods. Lab.*, 1958, **24**, (2), 254–255). Procedures are outlined for the determination of

Cu, Bi, Sn, Sb, As and Pb in ferrotungsten for works control.

Simplifed Method of Determining the Moisture Content of Materials Used in Welding. V. M. Shpeizman and E. A. Krasovskaya. (*Zavods. Lab.*, 1958, **24**, (2), 187–188). A simple method is described of analysing welding fluxes for moisture content.

The Use of Trilone B for the Determination of Iron in Ores and Sinters. N. G. Pesyenko. (*Zavods. Lab.*, 1958, **24**, (1), 25–26). A method is described for the determination of iron in ores and sinters. A HCl solution at a controlled pH value is titrated with Trilone B, in the presence of sulphosalicylic acid.—L. D. B.

Polarographic Determination of Chromium in Ores. J. Průša and E. Skokan. (*Chem. Listy*, 1958, **52**, (5), 915–917).

A Contribution to the Rapid Analysis of Blast-furnace Slag. A. Neuberger, E. Schöffmann and K. Herkenhoff. (*Arch. Eisenhütt.*, 1958, **29**, Jan., 35–39). Methods of analysing blast-furnace slags by photometry and flame photometry are described which enable the content of SiO_2, Al_2O_3, CaO, MgO, Mn and Fe to be determined accurately within 25 minutes.—L. J. L.

The Determination of the Sulphur Content of Solid Fuels. A. Zorner. (*Arch. Eisenhütt.*, 1958, **29**, Jan., 23). Five laboratories determined the total sulphur content of three coal and three coke samples in accordance with the German Standard DIN51724 to assess the suitability of the standard. The results indicated the standard.—L. J. L.

Direct-Reading Analysis of Steel Solutions Using a Reservoir-Cupped Centrepost Electrode. L. C. Flickinger, E. W. Polley and F. A. Galletta. (*Anal. Chem.*, 1958, **30**, Aug. part 1, 502–503). Mo, Si, Al, Cu, Ni, Mn, Cr and Pb can be determined.

Metallurgical Applications of the Spectrographic Determination of C, Si, Mn and P in Iron and Steel. J. Massmon and M. Jonckers. (*Rev. Tech. Luxembourg*, 1957, **49**, Oct.-Dec., 203–208). The authors discuss the principles of spectrographic analysis and the layout of their laboratory. A prism instrument with photo-multipliers is used. The application of this method to routine analysis of iron and steel is discussed.—R. P.

On the Spectrochemical Determination of Phosphorus in Steel with the Phosphorus Line 3175 Å. S. Eckhard. (**Arch. Eisenhütt.*, 1958, **29**, Feb., 89–94). In experiments with the object of determining P in steel with the P line 3175 Å according to H. Krempl and F. Bertram (*Phys. Rev.*, 1937, **51**, 726–735) it was found to be impossible to excite the 3175 Å line. The reasons for this failure are discussed.

Spectrophotometric Determination of Molybdenum as the Quercitin Complex in a Benzoin α-Oxime Chloroform Ethyl Alcohol Medium. G. Goldstein, D. L. Manning and O. Menis. (*Anal. Chem.*, 1958, **30**, Aug. part 1, 539–542). Tungstate and vanadate interfere.

Operating Experience with Flame Spectrometers in the Determination of Calcium and Magnesium in Steel Works Laboratories. K. Abresch and W. Dobner. (*Arch. Eisenhütt.*, 1958, **29**, Jan., 25–34). A quartz prism flame spectrometer is used to determine the CaO and MgO contents. Concentrated strontium chloride solution is added to counteract the effect of the solvents. In blast furnace slags the effect of SiO_2 on Ca determination is considerably reduced by the addition of strontium chloride. The SiO_2 is therefore evaporated with hydrofluoric acid or filtered off. Tables and diagrams are given and emissivity; information is given on results, errors, reproducibility and duration of tests.—L. J. L.

Application of Infra-Red Spectroscopy to the Determination of Mineral Constituents in Slags and Refractory Systems. W. Pepperhoff. (*Arch. Eisenhütt.*, 1958, **29**, Mar., 153–158). The infra-red absorption spectra of the mineral constituents in refractory materials and slags were measured between 6 and 14 μ, samples being prepared by the KBr pressure technique. Aluminium silicate, calcium aluminium silicate, calcium orthophosphate, apatite and calcium silicophosphate were investigated. It is concluded that the separation of compounds and phases achieved prove the value of this method of analysis.

Identification of Some Constituents of Steels and Pig Irons by Their Debye-Scherrer Patterns. F. Marion and R. Faivre. (*Rev. Mét.*, 1957, **54**, Sept., 725–732). An illustrated review of the application of X-ray diffraction techniques to the analysis of steel structures and inclusions is presented.—B.G.B.

INDUSTRIAL USES AND APPLICATIONS

The Manufacture of High-Pressure Vessels. J. H. A. Wennink. (*Lastechniek*, 1958, **24**, June, 101–103). The details of manufacture are given of two types of welded high-pressure reactor vessels; one type was made from 1% Cr, 0·5%Mo steel, and the other from 0·5% Mo steel clad with 18–8 stainless steel.

Steels for Welded Structures and Pressure Vessels. G. P. Smedley. (*Rev. Mét.*, 1958, **55**, Apr., 323–332). The requirements of a routine test for proving the notch toughness of steels are considered and details are given of several steels suitable for weldments. The use of such steels is examined in relation to service stressing, operating temperature, conditions of construction and residual stress. While notch-tough steels may reduce the chances of major failure under low temperature and adverse stress conditions it is emphasized that they do not permit latitude in the quality of welding.—B. G. B.

The Application of Alloy and Special Steels in Railway Work. H. O'Neill. (*Nat. Metallurgical Lab., Council of Sci. and Ind. Res., Jamshedpur*, 1958, 434–439). Properties needed for various parts are briefly noted. **Silicon Steel Sheets: An Outline of Properties, Applications and Recent Developments.** J. McFarlane. (440–447). Electrical uses are noted and Indian production is referred to. **Application of Alloy Steels to the Aircraft Industry.** V. Cadambe. (448–454). Requirements for various parts are set out. **Application of Stainless Steels in Nuclear Technology.** N. B. Prasad and G. S. Tendolkar. (455–457). **Problems in the Application of High-Strength Steel Alloys in the Design of Supersonic Aircraft.** A. F. Ensrud. (*S.A.E. Trans.*, 1958, **66**, 118–136). Conditions encountered under various flight conditions are set out, especially thermal conditions, and properties of materials and factors in design are discussed in some detail.

HISTORICAL

New Literature on the History of Iron. K. Schib. (*Nachr. Eisen-Bibl. Georg Fischer A.G.*, 1958, July, pp. 4). Reviews of recent books and of older literature are given.

Mining in Ancient Times. O. Paret. (*Giesserei*, 1958, **45**, Jan. 30, 65–68). Copper deposits in central Europe are described Examination of the ore deposits and discoveries on the Mitterberg (Austria) are also described: these include the mining, preparation and smelting of the ore. Gold, silver, lead and tin deposits and their mining in various parts of Europe (including England) are described in an historic vein. Finally, the discovery of iron in the Orient in about 1500 B.C. and in central Europe in 800 B.C. is considered together with its subsequent mining and smelting.—R. J. W.

The Earliest Use of Coke for Iron Making. R. A. Mott. (*Year Book Coke Oven Man. Assoc.*, 1958, 142–165). A careful review of all the evidence of the work of Abraham Darby.

Nitriding of Iron Was Used by the Ancients. J. R. Marechal. (*Métaux-Corrosion-Indust.*, 1958, **33**, Mar., 133–137). The results of metallographic examination of a Gallo-Roman hammer head shows the presence of iron nitride. A review is made of metallographic structures found in ancient steel objects, which show that iron nitride is not uncommon and it is suggested that nitriding was known in ancient times.—B. G. B.

ECONOMICS AND STATISTICS

Mathematical Statistics in Iron and Steel Works. Part I. Regression Analysis. H. Knüppel, A. Stumpf and B. Wiezorke. (*Arch. Eisenh.*, 1958, **29**, Aug., 521–533). A method of conducting a regression analysis is described which is suited to the conditions found in iron and steelmaking practice. The procedures are simplified as far as possible, and a complete example is worked out for the case of basic essemer Bsteel manufacture.

The Use of Statistics in Metallurgy. M. Knotek, J. Likeš and R. Vojta. (*Výzkumné Práce z Oboru Železa a Oceli, State Publ. House of Tech. Lit., Prague*, 1958, 7–26). [In Czech]. Statistical methods are explained and their application to metallurgical problems are discussed. In particular, reference is made to problems such as the effect of process variables in production and forging of tube steels on quality, the influence of production technology on the quality of transformer steels, and problems concerning the structures of some steels, which were recently solved by statistical methods.—P. F.

BOOK NOTICES

HANSEN, MAX. "*Constitution of Binary Alloys.*" (Prepared with the co-operation of Kurt Anderko). 2nd edition. 9 × 6 in., pp. xix + 1305. Illustrated. New York, Toronto, London. 1958: McGraw-Hill Book Publishing Co. Ltd. (Price £12 12*s.*).

"Der Aufbau der Zweistofflegierungen" by Dr. Max Hansen which appeared in 1936, was a widely acclaimed work, is now with the co-operation of Kurt Anderko superseded by this completely revised edition published in English. It is claimed that the literature has been searched up to the Spring of 1955. A notable feature of the work is that references for the years 1956 and 1957 are considered either in a supplement to the text or in notes added at the proof stage, while reference is made to some 1958 publications. The references appear to cover the field most adequately without any apparent bias to any country. The authors have carefully examined the information in the literature and their final conclusions have been incorporated in many of the composite diagrams. Although certain published results are frequently considered unreliable the authors do not always indicate why certain findings are given preference.

Readers will be pleased to see that the majority of the diagrams have been drawn on a Degree Centigrade–Atomic per cent. Grid with an auxiliary scale showing weight per cent. The mode of presentation is strictly alphabetical and about 1 380 systems are mentioned together with 750 diagrams, some of these being added at the proof stage. Alloys of Aluminium, Copper, Iron, Niobium, and Thorium are reviewed in 58, 55, 58, 36, and 35 systems respectively. A number of systems are dismissed in not more than three lines. On the other hand, some reviews extend over several pages. Four pages with 98 references are devoted to the Copper–Zinc system and the Iron–Carbon system is well reviewed in nine pages with 135 references. In general, the text is much more restricted than in the first edition but the field is very much wider. The supplements and the notes added in proof are most useful and in all cases the text and the diagrams should be used together. Some of the diagrams show a variation in the melting temperature of the element. For example, the metal iron is shown as 1 539° C in the Fe–Cr system and as 1 528° C in the Fe–Si system. If the text is not used in conjunction it might be inferred that an old diagram has been used in its entirety. If the Fe–Si system is used to illustrate the point it will be seen that the gamma loop is taken from data published in 1954 whilst the rest is essentially

from results in the year 1930 with amendments from work published in 1940.

One great improvement is the systematic consideration of the crystallographic data. The parameters are almost invariably given in Ångström units and in some cases a conversion from kX units has been made during the compilation. A twenty page appendix contains tables of structural data, temperature conversions, and Atomic to Weight per cent. conversions. The book, undoubtedly the best of its kind, contains about 1 300 pages and the print is clear. Many metallurgists will want to purchase a copy, the only deterrent is the price—£12 12*s.* 0*d.*—A. J. MacDougall.

"*Proceedings from the International Symposium on the Annealing of Low Carbon Steel.*" (Held at Case Institute of Technology, Cleveland, October 29, 30, 1957). 11 × 8½ in., pp. 138. Illustrated. Cleveland, Ohio, 1958: Lee Wilson Engineering Company, Inc.

The sponsors of a symposium on the annealing of low carbon steel have published the proceedings in a rather expensive but competently edited book. The process is dealt with from both the production and technical viewpoints with the emphasis perhaps on the former. Hindson, Miller, and Campbell, respectively, present papers concerning the importance of the processing practices of hot rolling and cleaning; time and temperature of annealing; and the annealing atmospheres on the final quality of the annealed product. Of a more fundamental metallurgical character are those papers by Morgan, Burns, and Heyer, and Niebch which deal with ageing, anisotropy and the kinetics of continuous annealing. An excellent paper specifically concerned with tinplate, on the effects of variation in the annealing cycle and chemical composition on the mechanical properties is presented by Marshall and Bauscher. On the economics of annealing Gulley presents some very interesting costing data applicable to the American scene. The costs of annealing in the British field are also touched upon in an extremely comprehensive summary by Ascough outlining the plant and practices employed at the various Steel Company of Wales works. There is a very interesting paper by Glinkov on a new type of furnace for the melting of low carbon mild steel which appears very much out of place in this Symposium.

The papers are of a high standard and are invaluable to all those concerned with the production of low carbon annealed sheet, strip, and blackplate. There are two criticisms that can be levelled. Whilst it is true that there are common threads running through the production of both tinplate and the thicker gauge sheet and strip it might have been advisable to have dealt with them in separate sections because of the profound difference in properties of the end products. Secondly an even more balanced programme would have been obtained by the inclusion of a paper by a metal physicist dealing with the underlying fundamentals on which this annealing process is based.—S. Garber.

"*The Structure of British Industry.*" A Symposium edited by D. L. Burn. The National Institute of Economic and Social Research. Economic and Social Studies, XV. 2 vols. 9 × 6¼ in. Vol. 1: pp. xvii + 403. Vol. 2: pp. xii + 499. Cambridge, 1958: The University Press. (Price: Vol. 1, 45*s.*; Vol. 2, 50*s.*).

Carter, C. F., and B. R. Williams. "*Investment in Innovation.*" On behalf of the Science and Industry Committee. 8½ × 5½ in., pp. ix + 167. London, 1958: Oxford University Press. (Price 15*s.*).

Both books are written for laymen as well as for economists. At a time when the ownership and control of the British Steel Industry are again matters of public discussion, there should be many people engaged in Research and Management who would profit from reading the chapter on steel in "The Structure of British Industry." Mr. Burn, who edits this book, is himself responsible for writing this chapter. A new edition of his monumental economic history of the British Steel Industry is expected shortly, but meanwhile we have this short account of his views of recent events. As usual, Mr. Burn's analysis is stimulating, even if sometimes mildly irritating to those engaged in the industry! There is, however, no doubt that this is a most well informed commentary on the industry from just outside.

Eighteen other industries are also described by University Teachers of Economics who have made a special study of them. On the supply side are ranged Transport, Coal, and Oil: the Motor, Shipbuilding, and Cutlery industries are important consumers of steel. The National Institute of Economic and Social Research has again put Industry in its debt by sponsoring this anatomical description of a sector of British Industry, which covers 40% of total industrial employment. It is heartening to find such a strong team of University Economists so well acquainted with business. Many acquired much of their industrial experience in their war-time activities, and certainly no comparable team would have been available before the war.

"Investment in Innovation" is a sequel to "Industry and Technical Progress" by the same authors, which was reviewed in the *Journal* in January, 1958. The same material is used in this study which is deliberately restricted to the investment decisions arising from new technical knowledge. It says many wise things about the process of converting technical discovery into industrial production.—E. T. Sara.

NEW PUBLICATIONS

British Standards Institution. B.P. 3035: 1958. "*General Recommendations for The Sampling of Manganese Ore.*" 8¼ × 5¾ in., pp. 10. Illustrated. London, 1958: The Institution. (Price 4*s.*).

British Standards Institution. B.P. 3029: 1958. "*Determination of Compressibility of Metal Powders.*" 8¼ × 5¾ in., pp. 6. Illustrated. London, 1958: The Institution. (Price 3*s.*).

British Standards Institution. B.P. 1501–1506: 1958. "*Steels for Use in the Chemical, Petroleum and Allied Industries.*" 11 × 8½ in., pp. 84. London, 1958: The Institution. (Price 25*s.*).

British Standards Institution. B.S. 1510: 1958. "*Steels for Use in the Chemical, Petroleum and Allied Industries. Low Temperature Supplementary Requirements to B.S.* 1501–1506." 11 × 8½ in., pp. 6. London, 1958: The Institution. (Price 4*s.* 6*d.*).

"*1958 Canadian Trade Index.*" 10 × 6½ in., pp. 1083. Toronto, 1958: The Canadian Manufacturers' Association. (Price $10.00).

Dreyer, Georg. "*Festigkeitslehre und Elastizitätslehre.*" 8vo, pp. xii + 420. Illustrated. Leipzig, 1958: Fachbuchverlag. (Price DM. 10.80).

Gagnebin, Albert P. "*The Fundamentals of Iron and Steel Castings.*" 9 × 6 in., pp. 78. Illustrated. New York, 1957: The International Nickel Co. Inc.

Gregory, E., and E. N. Simons. "*The Heat Treatment of Steel.*" 2nd edition. 8½ × 5½ in., pp. xiv + 381. Illustrated. London, 1958: Sir Isaac Pitman & Sons Ltd. (Price 35*s.*).

"*Handbook of Automation, Computation, and Control.*" Vol. 1. Edited by E. M. Grabbe, S. Ramo, and D. E. Wooldridge. 9 × 6 in., pp. xx + 26 chapters [not continuously paginated] + Index. Illustrated. New York, London, 1958: John Wiley & Sons, Inc., Chapman & Hall Ltd. (Price £6 16*s.*).

"*Handbook of Physics.*" Edited by E. U. Condon and H. Odishaw. 9¾ × 7 in., pp. xxxvi [+ 1 504, not continuously paginated]. Illustrated. New York, Toronto, London, 1958: McGraw Hill Publishing Co., Ltd. (Price £9 14*s.*).

Hansen, M. "*Durchflussmessung.*" Mitteilung Nr. 348a der Energie-und Betreibswirtschaftsstelle (Wärmstelle) des Vereins Deutscher Eisenhüttenleute. 11¾ × 8¼ in., pp. 36. Illustrated. Düsseldorf, 1958: Verlag Stahleisen m.b.H. (Price DM. 7.–).

"*A History of Technology.*" Edited by Charles Singer *et al.* Vol. 5. The Late Nineteenth Century c. 1850–c. 1900. 9¾ × 7¼ in., pp. xxxviii + 888. Illustrated. Oxford, 1958: The University Press. (Price £8 8*s.*).

Institut National des Sciences et Techniques Nucléaires. "*Symposium de Métallurgie Spéciale.*" Saclay, les 27 et 28 Juin 1957. 10½ × 8¼ in., pp. 128. Illustrated. Paris, 1958: Presses Universitaires de France.

Kubaschewski, O., and E. Ll. Evans. "*Metallurgical Thermochemistry.*" 3rd edition. International Series of Monographs on Metal Physics and Physical Metallurgy. Vol. 1. 8½ × 5½ in., pp. ix + 426. Illustrated. London, 1958: Pergamon Press Ltd. (Price 63*s.*).

Lipson, H., and C. A. Taylor. "*Fourier Transforms and X-Ray Diffraction.*" 8¾ × 5½ in., pp. vii + 76. Illustrated. London, 1958: G. Bell & Sons Ltd. (Price 18*s.* 6*d.*).

Neuber, H. "*Kerbspannungslehre.*" 2. Auflage. 9 × 6 in., pp. ix + 225. [+ 10 sheets in pocket]. Illustrated. Berlin, 1958: Springer-Verlag. (Price DM. 86.–).

"*Progress in Non-Destructive Testing.*" Vol. 1. Edited by E. G. Stanford and J. H. Fearon. 9¾ × 6 in., pp. vii + 267. Illustrated. London, 1958: Heywood & Co. Ltd. (Price 60*s.*).

"*Progress in Semiconductors.*" General editor: A. F. Gibson. Vol. 3. 9¾ × 6 in., pp. vii + 210. Illustrated. London, 1958: Heywood & Co., Ltd. (Price 55*s.*).

"*Radioisotopes in Scientific Research.*" Proceedings of the International Conference held in Paris in September 1957 under the auspices of U.N.E.S.C.O. Edited by R. C. Extermann. 4 vols. 10 × 6¼ in. Illustrated. Vol. 1: Research with Radioisotopes in Physics and Industry, pp. xxi + 761. Vol. 2: Research with Radioisotopes in Chemistry and Geology, pp. xxi + 741. London, 1958: Pergamon Press Ltd. (Price £7 per volume).

Ruhfus, H. "*Warmbehandlung der Eisenwerkstoffe.*" (Buchreihe "Stahleisen-Bucher" Band 15.) 9 × 6¼ in., pp. xii + 483. Illustrated. Düsseldorf, 1958: Verlag Stahleisen m.b.H. (Price DM. 52.–).

Schiffers, Hans, Dieter Ammann, Erich Brugger und Rudolf Dicke. "*Härtbarkeit von Gusseisen mit Lamellen-und Kugelgraphit in Abhängigkeit von Zusammensetzung und Gefüge*" Forschungsberichte des Wirtschafts-und Verkehrsministeriums Nordrhein-Westfalen. Nr. 557. 4to, pp. 29. Illustrated. Köln und Opladen, 1958: Westdeutscher Verlag. (Price DM. 11.–).

"*Untersuchung des Einfluss von Oberflächenfehlern auf die Dauerhaltbarkeit von Kurbelwellen.*" Bericht über eine Gemeinscheftsarb. des Schmiedausschusses des V.D. Eh. Erstattet von A. Th. Wupperman et al. 11¾ × 8¼ in., pp. 48. Illustrated. Düsseldorf, 1958: Verlag Stahleisen. (Price DM. 10.–).

"*Vacancies and other Point Defects in Metals and Alloys.*" A Symposium organized by the Institute of Metals and held at the Atomic Energy Research Establishment, Harwell, on 10 December 1957. Institute of Metals Monograph and Report Series, No. 23. 8½ × 5½ in., pp. 238. Illustrated. London, 1958: The Institute of Metals. (Price 40*s.*).

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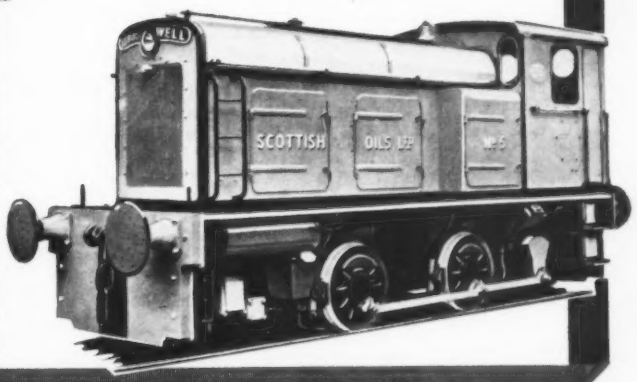

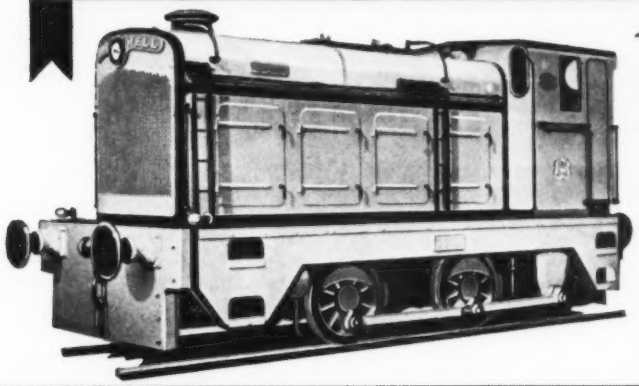

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Electrical Aids in Industry

Data Sheet **No. 3**

Induction Heating - 2

The broad principles involved in the use of induction heating for melting and processing metals have already been dealt with in this series (Data Sheet No. 2). In order to make a critical examination of its possibilities, however, the potential user should be aware of certain technical factors which must influence his decisions.

Induction heating, of course, demands the use of alternating current which is available from the public supply at a frequency of 50 cycles per second. Higher frequencies, however, are desirable for certain applications and can be obtained by means of the appropriate conversion equipment. Frequencies can therefore be considered in three categories:

Mains Frequency
(direct from mains)—50 c.p.s.

Medium Frequency
(machine generator)—50-10,000 c.p.s.

High Frequency
(electronic generator)—up to about 2,000,000 c.p.s.

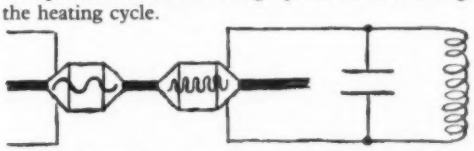
Mains Frequency

This needs no conversion equipment; it is particularly suitable for melting large pieces of scrap and, owing to the vigorous stirring forces produced, is excellent for alloy making. It has the merit of low initial cost compared with the high frequency method of melting, but is not so suitable for the production of high grade steel. Mains frequency induction heating is also useful for stress-relieving of welds in pipes and vessels, heating of chemical vessels, pipelines, injection moulding machines and press platens.

A typical example of the use of mains frequency is the coreless induction melting furnace which can be connected direct to the public 3-phase supply. Such a furnace rated at 120 kW, with a holding capacity of 2,240 lb., will give a throughput of 5,000 lb. per hour of hot cupola metal superheated from 1,350°C to 1,450°C.

Medium Frequency

Motor generators ranging from 10 kW to 1,500 kW or more at frequencies up to about 10,000 c.p.s. are widely used for heating for forging, melting from 100 lb. to 10 tons, hardening, annealing, etc. A bank of capacitors maintains a high power factor during the heating cycle.



Another form of generator for frequencies of 1 to 2 kc.p.s. and powers around 250 kW, useful for forge heating and melting high temperature aircraft alloys, is a 6-anode steel tank mercury arc inverter.

High Frequency

Metal hardening and metallurgical processing are best handled by high frequency induction (up to about 2,000,000 c.p.s.), particularly when a very thin case is required or when the section of the workpiece is too small to heat satisfactorily at medium frequency. These high frequencies are produced either by an electronic h.f. generator or a mercury-gap h.f. generator; high frequency induction can deal efficiently with such jobs as hardening lawnmower cylinders and cutters, bars and axle shafts.

The choice of frequency depends upon the metallurgical requirements and the size of the component to be treated. The following table gives the practical relationship between size and frequency, and may be used as a guide to the choice of generator, subject to metallurgical considerations.

Optimum Value

FREQUENCY C.P.S.	3,000	10,000	500,000	2,000,000
MIN. DEPTH OF HARDNESS POSSIBLE	.060 in.	.040 in.	.020 in.	.010 in.

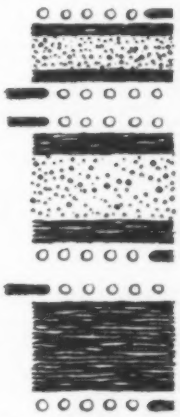
Practical Values

MIN. DEPTH HARDNESS EXPECTED	.150-.200 in.	.100-.150 in.	.030-.050 in.	.015-.030 in.
MIN. DIA. SURFACE HARDENING THIN CASE	2" & over	1" to 3"	½" to 2"	¼" to ½"
MIN. DIA. SURFACE HARDENING DEEP CASE	2" & over	2" & over	1" & over	not suitable
MIN. DIA. THROUGH HARDENING	1" & over	½" to 2"	¼" to ¾"	not suitable

These are of course very approximate since they also depend on metallurgical considerations.

Power required for H.F. Induction Hardening

The high frequency power required per sq. in. of hardened surface depends upon the amount of metal behind the surface. Higher powers and shorter heating cycles are necessary for thin cases and when the thickness of metal behind the surface is small.


0.03" to 0.04" requires 1 sec. or less at 10 kW or more per sq. in.
0.1" to 0.2" with a large mass of metal behind the surface, requires 10-60 secs. at 2 kW per sq. in.
Through hardening requires 10-12 kWh per lb.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association. Excellent reference books (8/6, or 9/- post free) are available on electricity and productivity—"Induction & Dielectric Heating" is an example.

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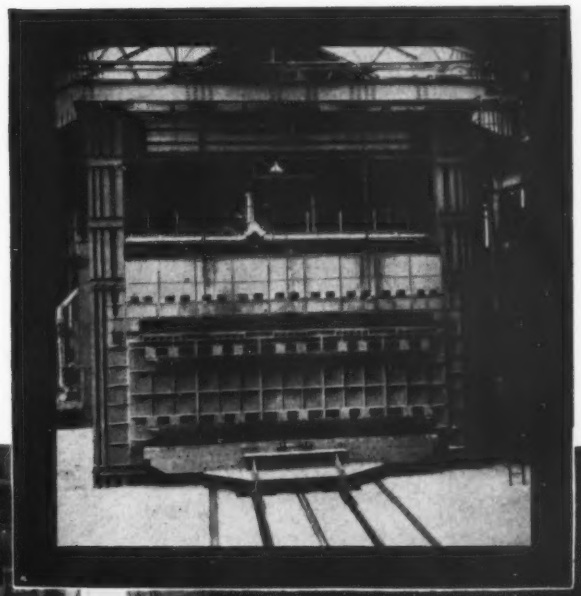

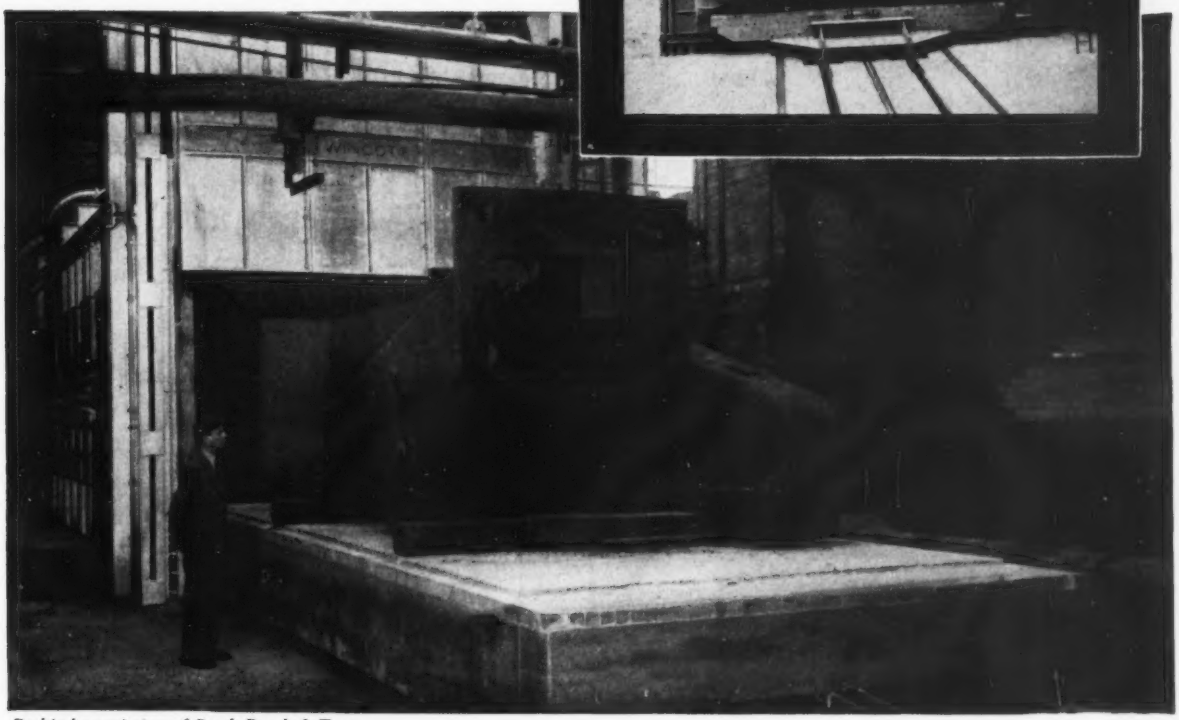

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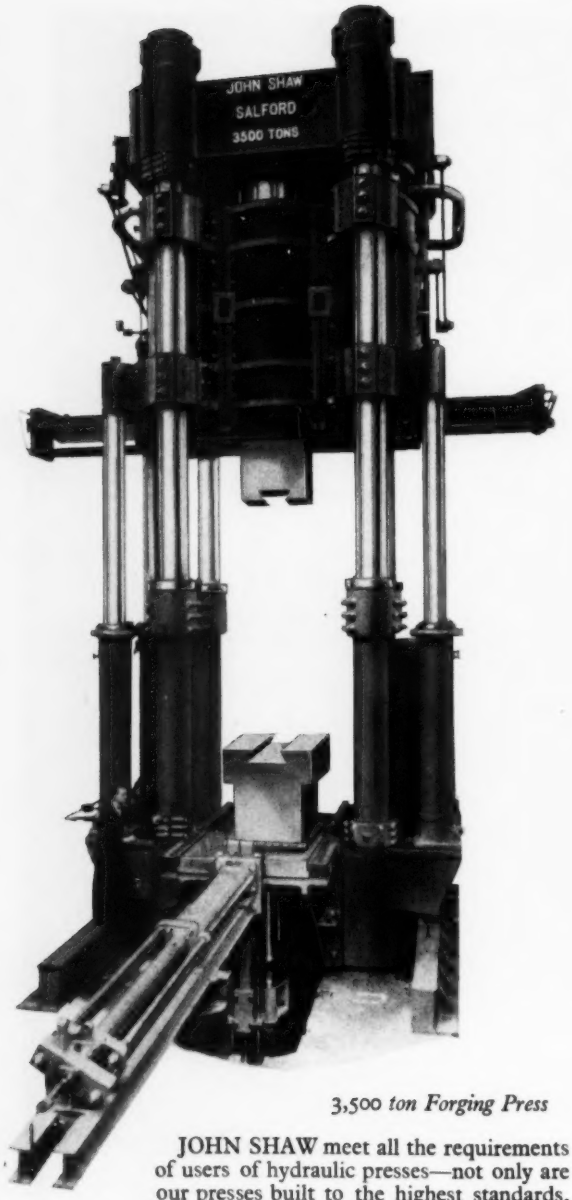

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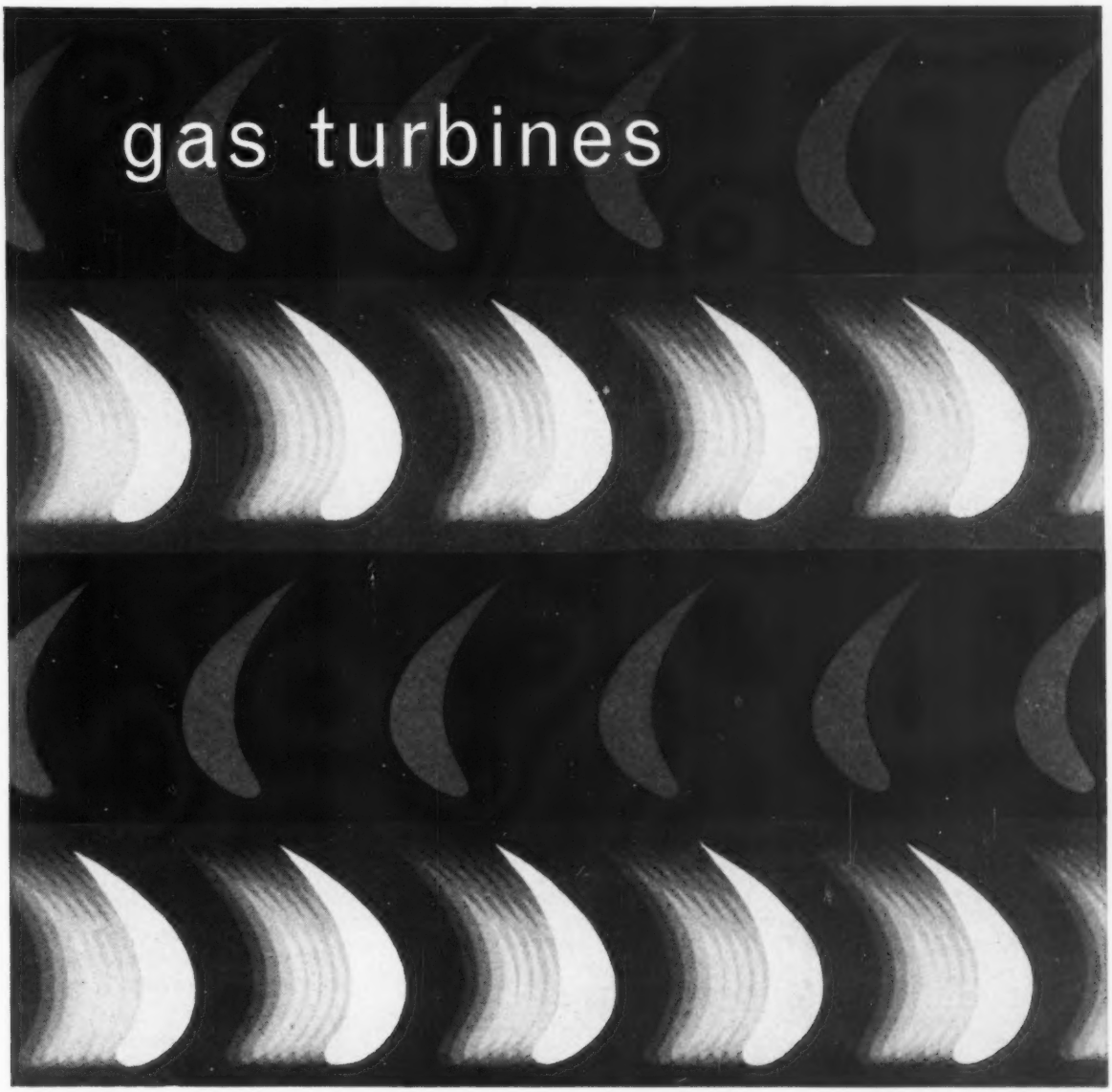

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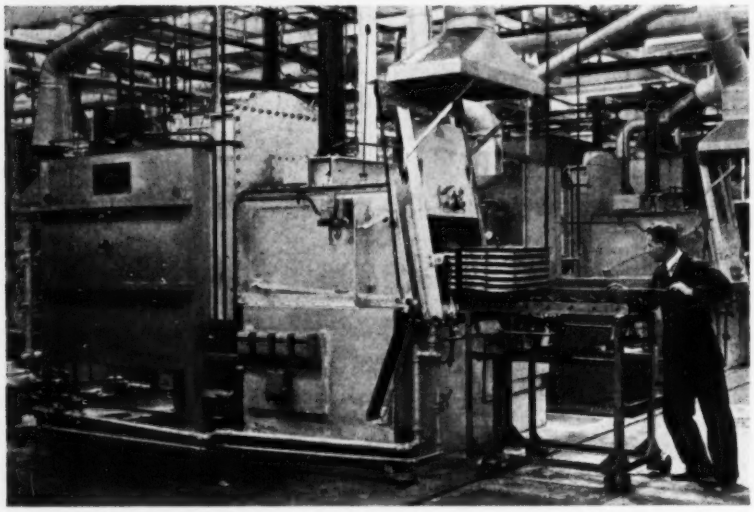

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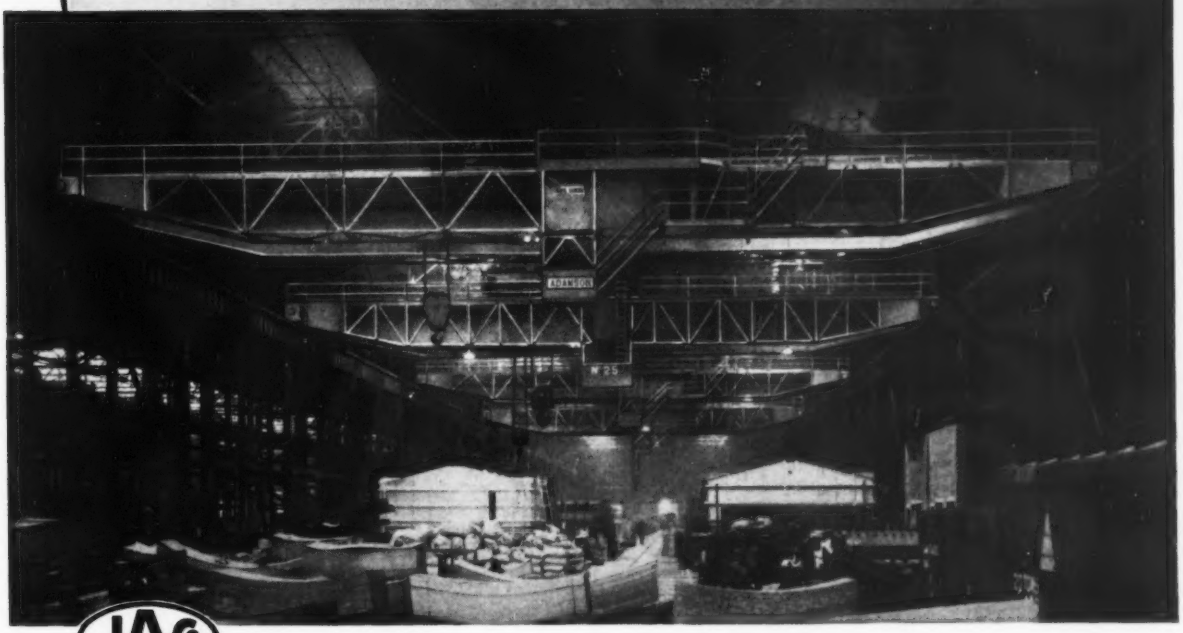

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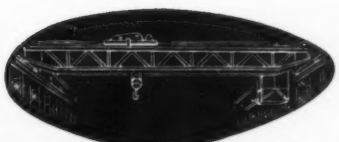

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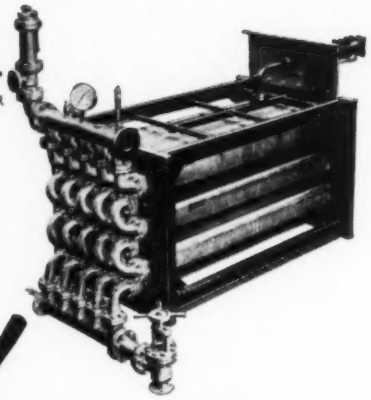

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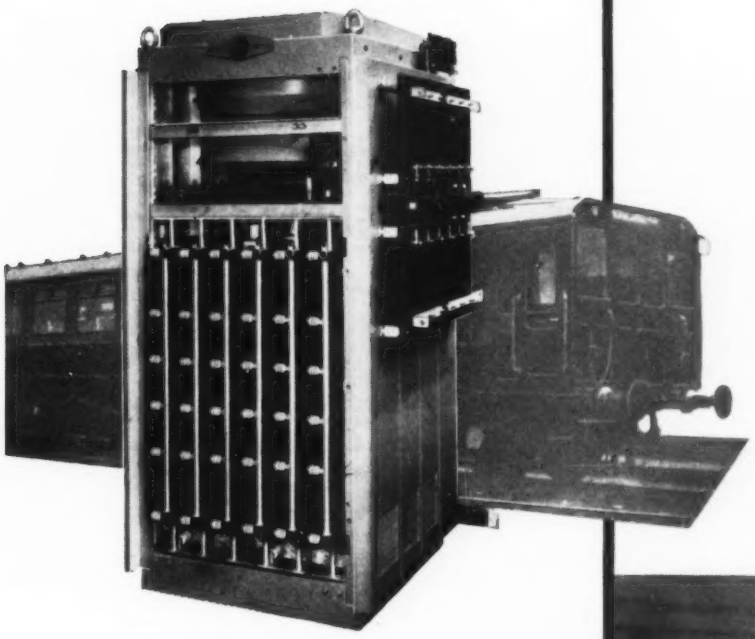

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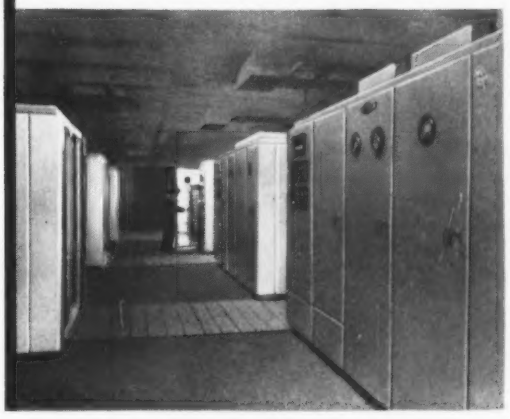

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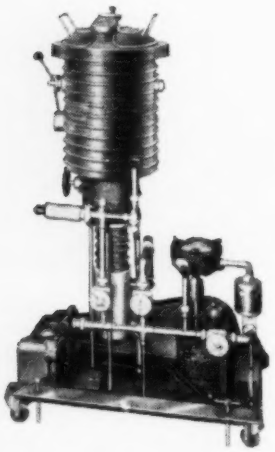

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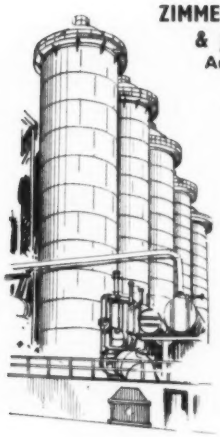

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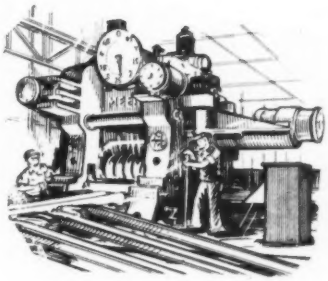

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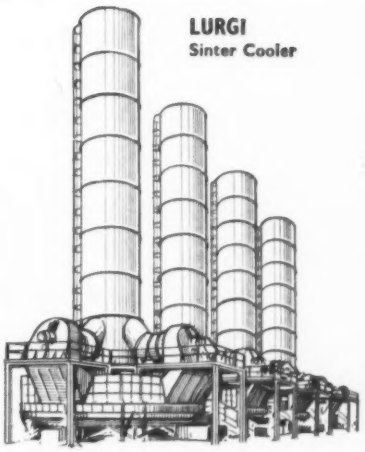

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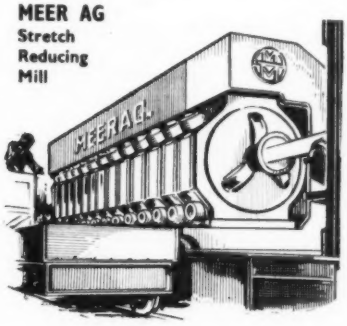

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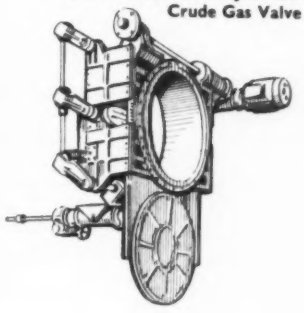

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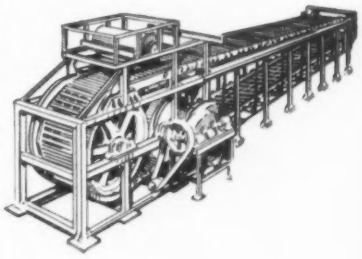

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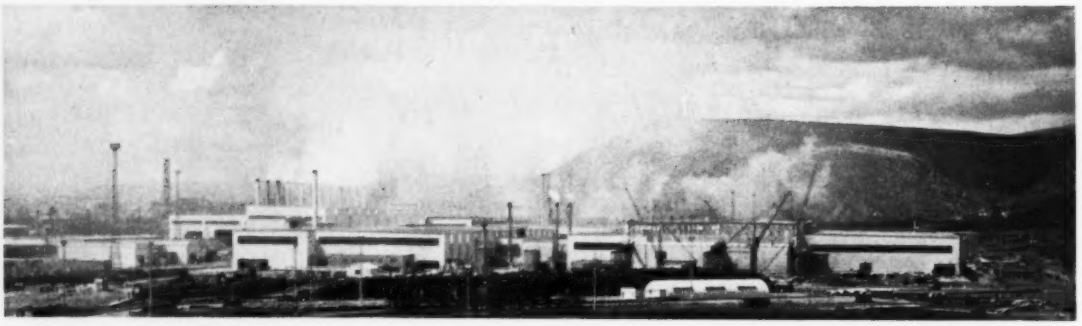

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ON 25th-26th September and on 11th-12th December, 1957, in anticipation of the Clean Air Act, 1956 and the Rivers (Prevention of Pollution) Act, 1951 coming into full effect in June and August, 1958 respectively, the Iron and Steel Engineers Group of the Institute held two meetings on Air Pollution and Water Pollution in the Iron and Steel Industry.

Twenty-five papers were written especially for the meetings, by authors from Austria, France, Germany, the U.S.A. and the U.K. During the meetings some lively and informative discussions took place, in which experts in a variety of fields gave their views. The papers, the reports of the discussions, and contributions received subsequently to the meetings, together with additional authors' replies, have now been published as a Special Report in one volume of 260 pp.

The report, No. 61 in the Special Report series of the Institute, is illustrated with over 200 diagrams and photographs and is bound in cloth with stiff board covers. Copies can be obtained from the offices of the Institute, 4 Grosvenor Gardens, London S.W.1, price £4 5s. 0d. (Members £4 5s. 0d.)

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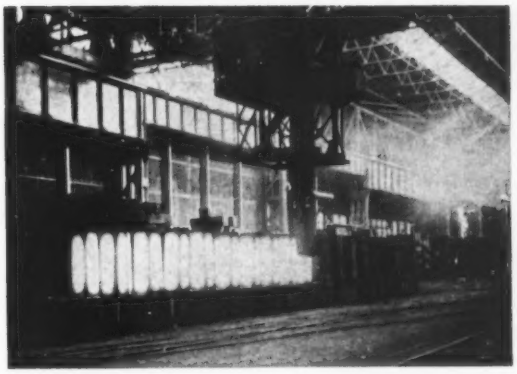

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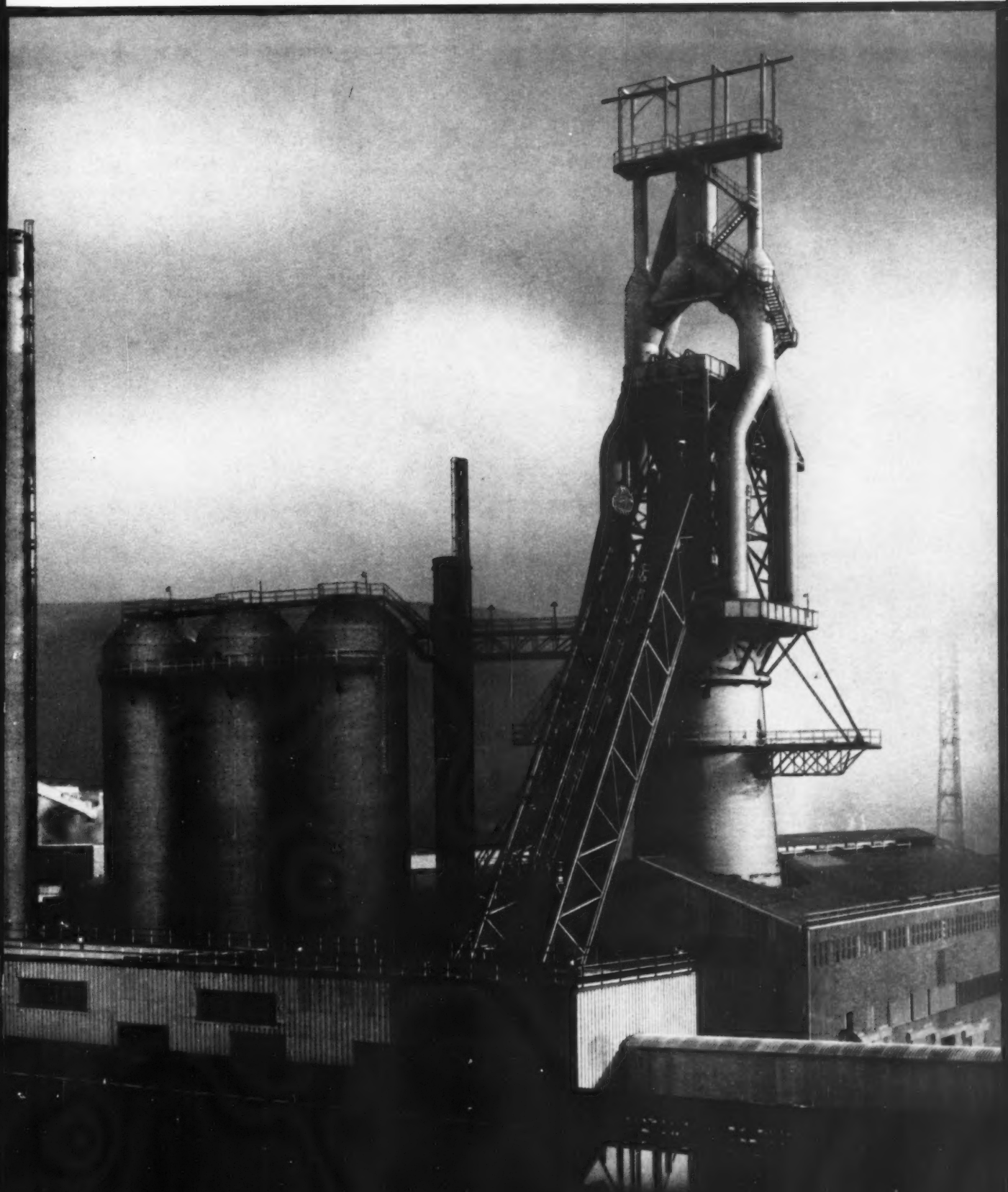

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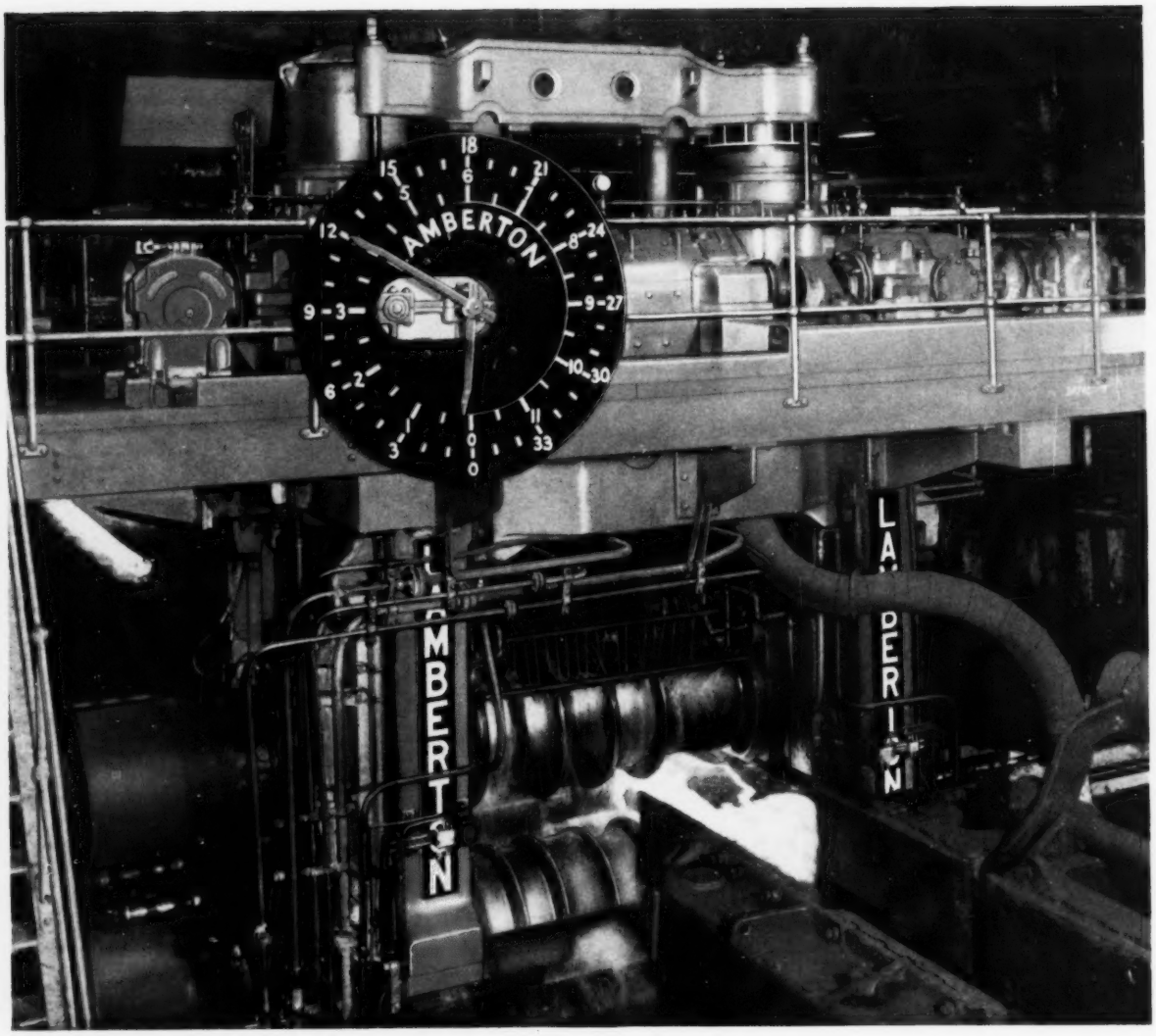

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